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TUNNEL COST-ESTIMATING METHODS

by

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The Office, Chief of Engineers (OCE), U. S. Army recognized the need for improving capabilities for estimating tunnel costs, improving support design, and overall, making tunnels and cavities more cost competitive with aboveground alternatives. Thus, the OCE requested that the U. S. Army Engineer Waterways Experiment Station (WES) conduct a study to develop and verify reliable methods for estimating costs of tunnel construction and establish improved (more cost-effective) methods for design of tunnel and cavity support systems.

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20. ABSTRACT (Continued)

This report describes an investigation of various tunnel construction cost-estimating techniques. Manual and computer methods are described and compared, important elements of tunnel construction are discussed, and an evaluation is made of the most promising computer cost model, using case histories of three completed tunnels for which good documentation was available.

The cost-estimating methods described herein can be used to develop more comprehensive and accurate estimates for tunneling than the method presented in EM 1110-2-502, Methodology for Areawide Planning Studies, MAPS, Part 2, Chapter 14, dated 28 November 1980. Plans are being made to improve the MAPS tunnel-cost functions to reflect the improvements identified during this study.

PREFACE

The study reported herein was performed under the RDT&E Program, Project 4A762719AT40, Work Unit E0/005 entitled "Improved Tunnel and Rock Cavity Support Systems," sponsored by the Office, Chief of Engineers (OCE), U. S. Army. Mr. D. S. Reynolds was the OCE Technical Monitor.

The investigation was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) during the period FY 77-FY 80. The study was conducted under the direct supervision of Mr. J. S. Huie, Chief, Rock Mechanics Applications Group (RMAG), Geotechnical Laboratory (GL), and under the general supervision of Dr. D. C. Banks, Chief, Engineering Geology and Rock Mechanics Division; Dr. W. F. Marcuson III, Chief, GL; and Dr. P. F. Hadala, Assistant Chief, GL. Mr. R. D. Bennett, RMAG, prepared the report.

Commanders and Directors of the WES during the investigation and preparation of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.8	square metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons per minute	0.003785	cubic metres per minute
inches	25.4	millimetres
miles (U. S. statute)	1.61	kilometres
pounds (force) per square foot	4.882	kilograms per square metre
pounds (force) per square inch	703.1	kilograms per square metre
pounds (mass) per cubic foot	16.02	kilograms per cubic metre

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

TUNNEL COST-ESTIMATING METHODS

PART I: INTRODUCTION

Background

1. Tunnel construction in the United States has been characterized as a high-risk, high-cost business. Cost overruns and delays have been especially damaging to public support for rapid transit tunnel projects and, to a lesser extent, to water tunnels. This support is critical since most tunnels are built and maintained with taxpayers' dollars. Consequently, decision makers have been forced to consider the following difficult questions:

- a. What factors cause these overruns, what is the relative impact of each factor, and what can be done to improve the assessment of these factors?
- b. What is needed to make tunnels more competitive with aboveground alternatives?
- c. The big question: Are these projects necessary and in the best interests of the taxpayer or are there better alternatives?

2. Much research has been sponsored by public agencies to find answers to these questions. Institutional factors have been studied (Mayo et al. 1968 and 1976, and National Research Council 1974). Such factors include the business climate, the reputation of the owner, the relative demand for tunnel construction and competing construction, which influences bid prices, risk, and profitability, and the general owner-engineer-contractor relationship. The barriers to technological innovation and to increased competition through the entry of new firms into the market have been studied, and recommendations have been made for improving the current situation. This report deals with one part of the overall problem; i.e., given the natural variability of underground conditions, the productivity of various combinations of men and equipment capable of constructing a tunnel, and the uncertainty of the economic climate, how reliable can the estimate of the cost of this planned

construction be? A companion question to which answers were sought was, what is the relative cost impact of each of the identifiable items of uncertainty?

Purpose

3. The purpose of this study was to develop or adapt reliable methods for estimating tunnel construction costs that could be used by planners and designers who are not necessarily tunnel experts or estimators.

Scope

4. This report presents the results of a study of tunnel cost-estimating methods. Important elements of tunnel construction are summarized and manual methods and computer models for estimating tunnel costs are described and compared in Part II. The computer model (COSTUN) was selected for in-depth study using case histories of completed tunnels. The three types of estimates prepared for each of the three selected case histories are as follows:

a. Estimates were prepared using all information known to be available to bidders. These estimates were compared with the engineer's estimate and contractor's bids.

b. Estimates were prepared using all information available at completion of the tunnel. These estimates were compared with the as-built cost and the preconstruction estimates and bids.

c. Parameter studies were made using all information known to bidders. Several estimates were prepared to assess the cost consequences of assigning different values to one factor while holding all other factors constant.

5. The results of the analysis of COSTUN using tunnel case histories are discussed in Part III, and the summary and conclusions are presented in Part IV. A complete user's guide for the COSTUN computer program is contained in Appendix A.

PART II: DESCRIPTION OF ESTIMATINC METHODS

6. In this section, a general discussion of tunneling and tunnel cost estimating is presented, and manual methods, including the use of cost curves, are discussed. Four computer models for estimating costs are described and compared.

Elements of Tunnel Construction

7. Before planning and estimating the cost of a tunnel, it is necessary to understand the different equipment and work methods that can be used to accomplish the job. Tunnel construction equipment may be divided into three main groups: (a) excavation equipment such as drills, jumbos, tunnel-boring machines, roadheaders, and mucking machines; (b) tunnel haulage equipment such as front-end loaders, trains, and conveyors; and (c) service equipment and facilities such as ventilation and air conditioning, generators, hoists, and lights. Although the selection of service equipment and haulage equipment is not much affected by the selection of the heading excavation method, the selection of excavation equipment is definitely dependent on this method. Parker (1970) and Mayo et al. (1968, 1976) provide thorough treatments of tunneling from different perspectives.

8. The actual construction of the tunnel consists of six main operations:

- a. Excavation.
- b. Muck disposal.
- c. Primary support installation.
- d. Pumping, grouting, or other ground control measures.
- e. Ventilation and air conditioning.
- f. Permanent lining installation.

The methods and timing for each of these operations may be varied to fit project requirements, site characteristics, and to some extent, designer or contractor preference. Excavation methods and equipment commonly

used are described in the following paragraphs. A more detailed discussion of various methods used in construction of tunnels and shafts is contained in EM 1110-2-2901 (Dept. of the Army, Office, Chief of Engineers (OCE), 1978).

Conventional tunnel
driving (drill and blast method)

9. Three major operations characterize this method of advancing a rock tunnel face. First, a burn cut is drilled at the center to allow room for rock expansion. Additional rings of holes are then drilled into the face on a predetermined pattern, using air or hydraulically operated drills mounted on a movable platform or jumbo. The holes are then loaded with dynamite or ANFO (a mixture of ammonium nitrate and fuel oil) and exploders that are connected to an electrical firing circuit. Men and equipment are then moved back a safe distance and the round is fired. After ventilation of powder fumes, the mucker is moved in and loads the broken rock into muck cars. Then the muck is transported to the surface and disposed of, the mucker is moved back, and the drill jumbo again advances to the tunnel heading to start another round. Depending on rock conditions, grouting to stop groundwater inflow, support placement, and exploratory drilling ahead of the face may be necessary before another round is drilled for explosives.

10. Major decisions that must be made in the planning stages of a conventionally driven tunnel include whether air, electric, or diesel power will be used and whether equipment will be rubber-tired or travel on rails. The basis for selection of power options and equipment mobility are covered in detail by Parker (1970) and are only summarized in this report.

11. Several variations may be used in conventional tunnel driving to accommodate special conditions. In good rock, full-face excavation is the favored method, but in poor rock or a mixed face, or in very large tunnels or caverns, heading and bench or multiple drift methods may be used. When heading and bench excavation is used, the top is normally driven portal to portal before excavating the bench. This practice allows the use of the drill jumbo in both operations. Prior to

about 1940, before jumbos became popular, the bench was usually excavated just behind the heading, with only a short 10 to 15-ft* working platform left.

12. Multiple-drift excavation is used when the crown must be continuously supported. Drifts may be driven at opposite springlines with rockbolts and shotcrete used for support. The rockbolts may extend transversely across the crown of the main tunnel so that it may then be safely mined. There are variations in the placement of drifts to meet special cases.

13. In a mixed-face excavation, part of the tunnel face consists of crushed rock or soft ground and the remainder is more competent rock. Forepoling or spiling is used to support the roof between the nearest steel set and the face. Sharpened wood spiles or steel rods are driven into the roof at a shallow angle from behind the nearest support and extended some distance beyond the face.

14. Blasting patterns vary for different conditions and because of contractor preference. The many options and factors that should be considered to develop an efficient blasting pattern are discussed in detail in EM 1110-2-2901 (Dept. of the Army, OCE, 1978). Blast holes are normally drilled either 8 or 12 ft deep. Two popular patterns are the angled cut and the burn cut. A combination of the two is also used. With the angled pattern, four cut holes are angled from the face to intersect at the axis and are heavily charged. Next, a ring of relief or easer holes is drilled, followed by one or more rings of enlarger holes, depending on the tunnel diameter. The outermost holes are the trim holes. Trim holes in the invert are called lifters. Successive rings are detonated after predetermined delays, starting with the cut holes at the axis. The trim holes are fired last. The lifters in the invert may be fired before or after the trim holes around the crown and spring lines, depending on the desired shape and size of the muck pile. The burn cut pattern uses one or more large diameter uncharged holes at the

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

axis to allow room for rock expansion when the outer rings are detonated. Again blasting proceeds from the easer holes to the trim holes, usually with predetermined delays between detonations of successive rings.

15. Jumbos for drilling the blast holes may run on the same track as rail muck cars or may straddle the muck car tracks on wide gauge rails, or in large tunnels, the jumbo may be rubber-tired. In small tunnels, with insufficient head space for a jumbo, lightweight air-leg drills may be used.

16. Mucking in small tunnels may be accomplished using a rail-mounted, air-operated, rocker-type shovel that loads the muck cars. In larger tunnels, an electric-powered mucker may scoop the muck onto a short conveyor section that dumps into the muck cars. The muck cars are pulled by electric or diesel-powered locomotives; if rail cars are used in steep-sloped tunnels, they may be winched. In very large tunnels, rubber-tired equipment is usually chosen for muck loading and hauling.

<u>Tunnels driven with a shield</u>

17. Shield-driven tunnels get their name from a steel plate shaped to fit the outside dimensions of the tunnel. The shield is used to prevent loose material from flowing or running into the excavation and must be jacked against the face. The miners excavate the face work under the front section of the shield, while supports are erected inside the rear section of the shield. As the face is excavated, the shield is jacked forward and slides past the previously erected supports. Tunnel support is transferred from the shield to the supports that may be cast iron, steel, or precast concrete segments. The annular space left by the thick shield plate is filled with pea gravel and grouted soon after jacking the shield forward. The use of a shield is dictated by poor ground that cannot be safely mined otherwise. In running ground, breastboarding at the face is required.

<u>Tunnels driven under air pressure</u>

18. Tunnels driven through soft ground below the water table or through crushed water-bearing rock zones require the use of compressed air in conjunction with the shield and partial or full breast boards at

the face. The air pressure is maintained by use of an air lock in the rear of the shield or at the portal. Sufficient pressure to balance the hydrostatic head is maintained forward of the air lock. Work hours are restricted proportional to the air pressure used, and a medical lock with a full-time attendant must be provided. Costs are proportionately higher for compressed air tunnels. The West Germans have recently introduced a successful slurry shield, the Hydrashield, which balances the hydrostatic pressure at the face with a bentonite slurry under pressure and thus eliminates the need for compressed air work.

19. Tunnels driven by boring machine (mole). This method of excavation replaces the cycle of drill, blast, and muck with (nearly) continuous simultaneous excavation and mucking. In soft, competent rock conditions, moles make faster progress than conventional driving methods. The mole or tunnel boring machine has a round rotating or oscillating cutterhead that may be fitted with any of several types of bits, teeth, or discs, depending on the type of material encountered. The material removed by the cutter is scooped from the invert by a muck bucket that rotates with the cutterhead. The muck is dumped on a conveyor belt and carried away from the face, either to the shaft or portal or to muck cars behind the mole. Moles may be used with shields in incompetent materials or soft ground, but better progress is made in soft, consistent rock where a shield is not necessary. Excavation in very hard rock wears down the bit very quickly; stratified rock or mixed face results in uneven thrust and excessive bearing wear and can cause large rocks to jam between the tunnel wall and rotating cutterhead.

Tunnel Estimating

20. Tunnel estimating is the art of conceiving a job on paper and properly evaluating the cost of planned construction. The assumptions and decisions that form the basis for cost computations are made by comparing cost records of similar completed projects, assuming a synthetic organization of men and equipment and rates of material usage and progress, or a combination of the two. A cost estimate can be prepared

manually or with the aid of a computer, but the basic decisions that must be made are identical and often both methods are used as a check. To develop a synthetic model, the method of excavation must be chosen, types and amount of equipment selected, progress rates assumed, crew sizes and makeup decided, and man-days required to accomplish the job estimated. The actual estimate quantifies the cost of the various inputs, including equipment, labor, materials, supplies, supervision, and escalation. Normal contingencies, risk, interest, and profits are not included in the estimate but compose the markup added to the estimate to arrive at a bid price. Engineering design and inspection are usually absorbed by the owner and are not included in the estimate. On a manual estimate, an estimator sets down all computations and afterwards presents the quantities and costs on a spread sheet that must conform to the owner's format in the request for bids. For a computer estimate, production rates, crew sizes, wage rates, and work hours are among the necessary inputs to produce a tabulated cost estimate. There are disadvantages and advantages of each method. Probably no contractor has ever submitted a tunnel bid prepared solely by a computer; a manual estimate gives them more confidence in the assumptions and calculations used and serves as a check on the black box. On the other hand, the computer method allows an owner's representative to evaluate many alternatives to optimize route selection, support design, depth of cover, shape, excavation method, and other factors to arrive at the most economically feasible option in the time available. A hand-calculated estimate may then be prepared on the most promising alternatives as a check. Obviously, then the selection of the method depends on the intended use of the estimate.

21. The following paragraphs present a discussion of the procedures for preparing a detailed manual estimate, a preliminary estimate using unit cost data, and the use of cost curves.

Manual estimates

22. The steps involved in preparing a detailed manual estimate follow:

a. Obtain and study plans and specifications.

b. Inspect site.

c. Review aerial photographs, geological reports, and boring logs.

d. Tabulate quantity takeoffs.

e. Obtain quotes from suppliers, insurance and bonding companies, and subcontractors.

f. Determine wage rates.

g. Prepare construction schedule.

h. Select excavation method.

i. Select equipment.

j. Estimate cost of equipment rental or purchase.

k. Determine crew size and makeup.

l. Estimate progress rates.

m. Estimate cost of aboveground development.

n. Estimate cost of tunnel excavation supplies.

o. Estimate cost of tunnel excavation labor.

p. Estimate cost of support and lining supplies.

q. Estimate cost of plant.

r. Estimate cost of concrete-lining labor.

s. Estimate direct cost of other bid items.

t. Tabulate all direct costs.

u. Estimate indirect costs.

v. Estimate camp costs.

w. Estimate escalation.

x. Tabulate total estimated costs of project in format required by request for bid.

All the steps above are interrelated and must be checked back and forth. For example, the initial construction schedule may be altered several times, but the contract end date must be adhered to. Thus men and equipment may have to be added to accomplish some tasks more quickly. The plans and specifications will be referred to countless times, i.e., after the site visit to check the impact of new information gained about access, labor wage rates and availability and their impacts on particular excavation methods, blasting restrictions, availability and cost of

power and water, etc. The review of geological information may indicate that a favored method of excavation or groundwater control will not work, necessitating changes. It is a good idea to prepare a checklist, and as each step is completed, compare them to determine if there are conflicts that must be resolved before moving to the next step. Quantity takeoffs must be calculated for each supply item or task and tabulated for convenient identification and cost of every aspect of the job. Requests for quotations from equipment and materials suppliers are made at the earliest possible date, even before the excavation method is chosen, to nail down these costs. These quotes serve as the basis for evaluating alternative methods and equipment.

23. Wage rates and availability are usually determined during the site visit, but they may change before the contract is awarded and so must be watched carefully. Selection of the excavation method sets the stage for many of the subsequent decisions and must be carefully weighed against required equipment purchases versus equipment currently owned, required crew makeup, manufacturer's lead time, and a host of other factors. Currently owned machines are always favored if they are suitable for the tasks. Selection of muck haulage and service equipment is not much affected by the excavation method. Tunnel length, size, shape, distance to disposal, and time allowed for completion do have a major impact on types and numbers of equipment used. Similarly, crew size and makeup are dependent on methods and equipment used. The advance rates that can be achieved are tied to all these factors; the slowest unit of production is the controlling one. For example, a tunnel boring machine may be capable of excavating 50 ft per shift, but if it is mated with a muck removal system that is slower or breaks down often, the mole will never develop that rate. In drill and blast tunnels, the length of rounds must be balanced against the capacity and cycle time of the muck removal system. Juggling men and equipment, length of rounds, etc., may be required to achieve the best possible efficiency. In some cases, more men and equipment might speed up mucking, but limited work space in small tunnels might preclude this effort. In such a case, multiple headings or alternating headings may be advantageous. To

achieve a synchronized efficient advance rate with the least possible idle time is one of the most difficult, yet necessary, tasks in tunnel construction. It cannot be done with any finality on paper but requires continuous monitoring and the ability to adapt quickly to changing conditions.

24. When the best estimate of progress rates has been arrived at, the next step is to tally the direct and indirect costs of each pay item. Direct costs may be arranged in the following categories after the equipment, crew makeup, advance rates, and quantities have been set:

a. Access and supply logistics (mobilization).

b. Tunnel excavation.

(1) Labor.
(2) Materials.
(3) Equipment.

c. Primary support.

(1) Labor.
(2) Materials.
(3) Equipment.

d. Lining.

(1) Labor.
(2) Materials.
(3) Equipment.

e. Demobilization and salvage.

25. Indirect costs must be developed next. Checklists are time-saving aids for this task and can be used for insurance, plant, field overhead, and office supervision. The effects of inflation and the data used by the contractor to develop a cash-flow forecast must be checked. In some instances, the figures may be juggled to produce a more favorable cash flow during the early stages of the contract. This practice is known as unbalancing the bid. An owner's representative is less concerned about cash flow but must consider the yearly budget requests and needs of the owner if the tunnel is publicly owned. (Most tunnels are owned by state and federal agencies). The estimated costs, when totaled, will be the basis of the build-no build decision by the owner and the bid-no bid decision by the contractor. In addition, the contractor must consider other market conditions, including interest costs, minimum

attractive rate of return, business-mix objectives, key personnel, etc., and balance this job against other tunnel jobs or other heavy construction, each with its own set of potential rewards and penalties.

26. The steps required to manually estimate the cost of tunnel construction have been outlined. According to personnel in large tunnel construction firms, the average time required to prepare a detailed tunnel estimate is three weeks and ranges from two weeks to two months.

Unit cost method

27. The unit cost method of estimating tunnel costs is a well-accepted simple technique for making preliminary or planning estimates. It relies on historical records of similar jobs. Basically, the estimator prepares quantity takeoffs for the tunnel and determines the unit cost of each item by comparison with other similar tunnels. These costs may or may not be adjusted for inflation, regional differences, etc. The sum of the unit cost times the quantities of each item yields the tunnel cost. Obviously, this simplified method may not reflect the actual cost for several reasons: (a) differences in locations, construction methods, special site conditions, etc., are not accounted for and may not be recognized; (b) if unit cost data are developed from the three lowest bids, as is often the case, the common practice of unbalancing bids will distort the unit costs. However, the total cost may not be affected much because an unbalanced bid is just a redistribution of the total cost to improve cash flow in the early stages of a project; (c) unless adjustments are made for inflation, large errors may result; (d) bidding climate influences are not accounted for, such as the number of prospective bidders and number of competing jobs. However, only the profit margin would be affected, and since profit margin ranges from about 3 to 20 percent, this omission would not negate the unit cost method's usefulness for preliminary estimates or comparison of alternatives.

Tunnel cost curves

28. One of the earliest reported developments to improve the reliability and reduce the time required for preliminary tunnel estimates was made by the California Department of Water Resources (1959). Their

need for reliable preliminary estimates to aid in route selection led to the formulation of a family of "cost curves." Case histories were analyzed to determine the cost impact of all factors involved in tunneling. They considered four major construction items affecting cost: excavation, support, dewatering, and lining. For each item, a family of cost curves was developed. Each curve represented a specified geological classification. The curves were plotted as item cost per foot of tunnel versus tunnel diameter. This work was done before moles and other tunneling advances were widely used. Consequently, the curves were representative of costs for conventionally (drill and blast) excavated tunnels, using standard steel-set support design (Proctor and White 1946). Soft ground, cut and cover, and mole excavation were not considered. Only circular-shaped tunnels were analyzed. The cost-per-foot figures were lump sum, not subdivided for labor, equipment, and materials, or profit, contingency, and overhead. Prior to the years of rapid inflation, these curves served their purpose quite well. The estimator simply entered the family of curves with a known tunnel diameter and estimated the length of each representative geological classification, then found the appropriate cost per foot for his tunnel. The cost per foot multiplied by the length was the total segment cost. Segment costs were summed over the tunnel length to produce a total estimated cost of the tunnel. Inflation and advancing technology eventually eroded the reliability of the curves, but they were a starting point for estimators in following years.

Computer methods

29. The steps involved in preparing a tunnel cost estimate with the aid of a computer are identical with those required for a manual estimate. The input data must conform to the requirements of the particular model being used. Some models have subroutines built into them that allow crew sizes, advance rates, lining thickness, and ground control measures to be calculated internally. These internal calculations may be suppressed by direct input of the required parameters, manually overriding the calculated value. Other models require that all information be input, just as in a manual estimate. Four computer models were

investigated during this study. One important aspect to remember is that although computer models unquestionably save time on computations, the data-gathering phase is not shortened and represents the bulk of the time required for tunnel estimating. Important features of each of the four models are discussed in the following paragraphs.

COSTUN - A Computer Program for Estimating Costs of Tunneling

30. COSTUN was developed in 1973 by Harza Engineering Company under contract to the Federal Railroad Administration (FRA), U. S. Department of Transportation. Complete documentation of this program is contained in Report No. FRA-ORD&D-74-16 (Wheby and Cikanek 1973). The report is available through the National Technical Information Service, Springfield, Virginia 22151. Permission by the FRA to use excerpts from this report is gratefully acknowledged. The COSTUN program has been used extensively by Harza in their tunnel work and has seen considerable use by the U. S. Army Engineer Division, New England, on the Park River Tunnel Project. Its use on this project was reported by Blackey (1979). EM 1110-2-502 (Dept. of the Army, OCE, 1980), Part II, Chapter 14, presents a method for making rough planning estimates for tunnels. The cost calculations were based on cost curves for different size tunnels and various geologic conditions developed using the COSTUN program. The method described herein allows the user to develop a more comprehensive and accurate estimate. It must be remembered, however, that the accuracy of any estimating method depends on the accuracy of the required input data.

Program philosophy and general characteristics

31. The documentation report (Wheby and Cikanek 1973) states that the program's philosophy is to duplicate the thought and reasoning processes that take place in the detailed planning, design, quantity takeoffs, and estimate of cost of an actual tunnel and shaft system. To achieve this goal, construction operations that affect cost were divided into twelve components:

a. Excavation setup.

b. Excavation.

c. Muck loading.

d. Muck transporting.

e. Muck hoisting.

f. Muck disposal.

g. Supports.

h. Lining.

i. Lining formwork.

j. Grouting.

k. Pumping.

l. Air conditioning.

Each of these cost components was subdivided into labor, materials, and equipment cost subcomponents. Tunnels and shafts are considered separately in the program, but a similar division of cost components applies. The program was intended to have general application; therefore, fixed values were not assigned to these project dependent components. Rather, matrices of unit costs were developed for each component and subcomponent over a wide range of tunneling conditions, and equations were fit to these matrices and programmed. These unit costs were developed by studying past tunnel jobs, as well as current practices, and assuming synthetic organizations of men and equipment for various types and sizes of tunnel-shaft systems. Unit costs were based on 1969 Chicago prices for labor, equipment, and materials. Therefore, adjustments must be made for other times and locations. These cost adjustment factors must be provided by the user (guidelines are given herein) and consist of adjustments for labor, materials, equipment, and regional productivity differences. In addition, contractor's profit and overhead are required user input. The program does not consider the cost of any aboveground operations except cut and cover construction. Consequently, the costs of access roads, foundation underpinning, portal excavation, mitigation costs for loss of business revenue, traffic detours, right-of-way acquisition, and utility relocations must be separately calculated and added to the COSTUN estimate. Likewise, costs of architectural finish,

lighting, permanent ventilation, long-term pumping, and roadway or track construction must be separately estimated, where applicable, and added to the estimate. Since these costs and mobilization and demobilization costs may be quite significant, COSTUN is not recommended for estimating small jobs. In addition, COSTUN estimates would be inapplicable to one-of-a-kind jobs where innovative or unique equipment or techniques were used, for which there was no precedent when COSTUN was developed. In its defense, however, manual estimates for these jobs would probably be only slightly more accurate because they too base advance rates on assumptions from precedents.

32. Factors affecting the cost of a tunnel were grouped into three broad categories:

a. Site characteristics.

b. Design requirements.

c. Construction methods.

The variable factors within each category must be assigned values that form the input data. Input data for a tunnel-shaft system are stored by tunnel reach and segment numbers and shaft and segment numbers. A reach is defined as any number of contiguous segments driven from a single heading. (The number of reaches is equal to the number of faces worked.) A segment is defined as a continuous length of tunnel or shaft, within which all the factors affecting cost must be constant. The user must decide when the values of a particular factor may be averaged over a given distance and when a new segment must be created.

33. Design requirements and construction methods change abruptly when they change at all, so there is no problem in assigning segment limits based on these categories. However, site characteristics are seldom constant over any appreciable distance. Judgment and experience are necessary to determine what constitutes significant change in a factor or factors, requiring establishment of a new segment. A relatively small change in some factors, such as rock quality designation (RQD), would necessitate a new segment. Changes in other factors, such as density, are not so critical, and moderate ranges of density may be averaged within a segment. As part of this study, the impact on estimated

costs resulting from varying the input values of particular factors was examined for an expected range of values while holding all other factors constant. This sensitivity analysis provided insight into which factors were critical, requiring reliable quantitative determination, and which factors could be estimated with minimal effects on cost if the estimates were wrong.

Site characteristic factors

34. Some input factors are not required for certain tunnel types and excavation methods. Other factors, identified as optional input, may be input, or the user can allow the computer to calculate the values. Guidance on selection of parameter values is given in the documentation report (Wheby and Cikanek 1973). The required factors are as follows:

- a. Rock quality designation, RQD (Deere et al. 1969).
- b. Rock strength, unconfined compressive strength, psi, of intact specimen.
- c. Governing shear strength, psf (the material strength that controls its behavior).
- d. Saturated unit weight of soil or rock, pcf.
- e. Soil angle of internal friction, PHI, undrained.
- f. Soil cohesion, C, psf, undrained.
- g. Equivalent angle of internal friction, PHIEQ, for materials characterized by friction and cohesion.
- h. Effective grain size, D_{10}, mm.
- i. Groundwater elevation - average elevation of groundwater table for each segment.
- j. Sound rock elevation - the level below which the material in a cut and cover tunnel can be removed only by drill and blast methods.
- k. Segment depth, ft, from average ground surface elevation to average tunnel elevation.
- l. Impervious layer elevation - elevation of clay layer below which ground cannot be dewatered by pumping, or below which ground is sound rock.
- m. Permeability, cm/sec, for soft ground and cut and cover segments.
- n. Inflow, gpm, at the working face.

o. Distance to disposal, miles from exit shaft.

p. Cost of disposal site, dollars per acre.

q. Rock or soil temperature, degrees Fahrenheit.

r. Air temperature, degrees Fahrenheit.

Design requirement factors

35. Required input factors are listed below with options under the factors. The reader is again referred to the documentation report for complete descriptions and definitions.

a. Tunnel or shaft type.

(1) Underground heading.
(2) Cut and cover.

b. Shape.

(1) Circle.
(2) Horseshoe.
(3) Baskethandle (shape similar to horseshoe but with height approximately one-half that of same width horseshoe).
(4) Square.
(5) Single-level cut and cover box.
(6) Double-level cut and cover box.

c. Size.

(1) Characteristic finished inside dimension. Limiting tunnel and shaft sizes that may be run on COSTUN are minimum 10-ft and maximum 40-ft finished diameters.
(2) Characteristic nominal excavation dimension.
(3) Characteristic nominal excavation dimension plus overbreak.

d. Slope - tunnel slope up to 26 percent may be run on COSTUN (There are limits on the use of certain muck hauling methods for steep slopes; e.g., rail muck cars cannot be used if the slope is greater than 5 percent.).

e. Hoisting height.

f. Reach length.

g. Side slope (for cut and cover tunnels).

h. Stability number - based on Terzaghi's Tunnelman's Cround Classification System and stand-up time (Terzaghi 1950).

Construction method factors

36. Site characteristics and design requirements strongly influence the choice of construction methods, but some latitude exists. All

other things being equal, a contractor will choose methods with which he is familiar and that allow maximum use of equipment presently owned. Three of the factors listed below are required user input and three are optional; if no value is input, COSTUN will calculate them or use a default value, as explained below.

a. Construction work week - optional. If no value is input by the user, COSTUN uses a 6-day, 24-hr/day work week.

b. Soft ground stabilization method - optional. COSTUN will select the most suitable option for particular ground conditions if not input by the user.

c. Excavation method - required input. Options are conventional (drill or blast), mole (tunnel boring machine), cut and cover, hand excavation, and ripper excavation. In soft ground, the use of a shield is assumed by COSTUN.

d. Muck transport method - required input. Options considered are conveyor, trucks, rail cars, and combinations of conveyor and trucks. Limiting slope for the use of rail cars is ± 5 percent; if used on steeper slopes, they must be winched. Trucks cannot be used in compressed air or in tunnels with height less than 16 ft. Conveyors are permissible in all cases.

e. Advance rate - optional input. If not input by the user, COSTUN will calculate for each segment based on advance rate equations developed from previous jobs and equipment manufacturer's specifications. Appropriate adjustments are made, based on work hours, productivity loss during start-up, or when changing methods or starting a new segment or reach. Advance rate is one of the most critical input factors affecting the final cost estimate and should be considered carefully, whether calculated by COSTUN or input by the user.

f. Lining and support - required input. Supports are defined as the primary means of ensuring stability of the excavation. Options include rockbolts, wire mesh and shotcrete, steel sets and lagging, or segmental liners made of steel, precast concrete, or cast iron for underground headings. For cut and cover construction, slurry walls or soldier piles and lagging may be used. Lining is the secondary support. Its purpose is to protect the primary support against deterioration, as well as to enhance hydraulic properties in water tunnels. In COSTUN, the criteria presented by Deere et al. (1969) have been adopted for support and lining design. If other criteria are used in design, the COSTUN values might not conform to actual quantities and costs. Equations used by COSTUN in selecting the support and the lining type and

thickness are detailed in the text. Lining thickness and type may be input directly by the user, if desired.

37. Some factors or operations that may vary in actual tunnel construction were assumed constant based on accepted practice in 1970. These factors are discussed in detail in the documentation report and include:

a. Method and timing of lining erection.

b. Selection of specific equipment and production rates.

c. Range of conditions through which various methods are applicable.

d. Shaft inflow control methods.

38. The tunnel program philosophy and general structure have been presented. Actual user instructions for preparing a computer tunnel cost estimate using COSTUN are presented in Appendix A.

TCM - Tunnel Cost Model

39. The tunnel cost model (TCM) was developed in 1973 in its first phase* by researchers in the Civil Engineering Department at Massachusetts Institute of Technology (MIT) for the National Science Foundation's RANN (Research Applied to National Needs) Program. Permission by Dr. Michael Markow, MIT, to summarize the project's development is gratefully acknowledged. Complete documentation of the development, applications, and user instructions is contained in a comprehensive series of MIT publications.

Program philosophy and general characteristics

40. TCM is a rather large computer program, written in PL/I (IBM Machine Language I), and is run on an IBM 370/168 at MIT. Reported storage requirements range to 500K for the largest tunnel modeled. Subroutines accompanying TCM require region sizes up to 600K in which to compile.

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* A more comprehensive version was developed by Moavenzadeh and Markow (1978). Reported changes and improvements are discussed in this report in the sections in which they apply.

41. The "Summary Report" (Moavenzadeh et al. 1974a) states, "TCM was developed in an attempt to improve the assessment of uncertainty in rock tunnel cost estimates." All tunnel estimators try to assess risk and uncertainty on a job; their method usually consists of comparing the current job with similar previous ones, detailed assessment of plans and specifications, and using their experience and intuition to make subjective judgments about job risks. The philosophy behind TCM was to provide a method to quantitatively assess the impact of each item of uncertainty on costs and time. To achieve this goal, the model incorporates probability and statistics concepts that allow the user to subjectively specify the degree of confidence he has in each piece of input data. For example, instead of drawing up one geologic profile with fixed values of strength, RQD, etc., for each rock unit, the user may supply several possible values for each parameter used to describe a particular rock unit, with corresponding subjective probabilities assigned to each value. The computer model consists of three main components:

a. A geological submodel.

b. A tunnel simulator.

c. A construction submodel.

Geological submodel

42. The geological submodel stores input data according to the tunnel segment and rock unit. Unlike other computer models, more than one rock unit or type may be assigned to each segment. Each rock unit must be assigned a probability of occurrence. Typically, seven parameters may be used to describe each rock unit, such as rock type, major defects, RQD, foliation, gas, water inflow, and compressive strength.

43. Fewer or more parameters may be used as the user sees fit to describe the rock unit. This flexibility in segment and rock unit descriptions is made possible through the use of "parameter trees," as shown in Figure 1. Typical values, possible states, and construction consequences are presented in Table 1 for parameters typically used to form parameter trees.

44. In addition to the probabilistic states assigned to segments, the physical boundaries of the segments within which these states are

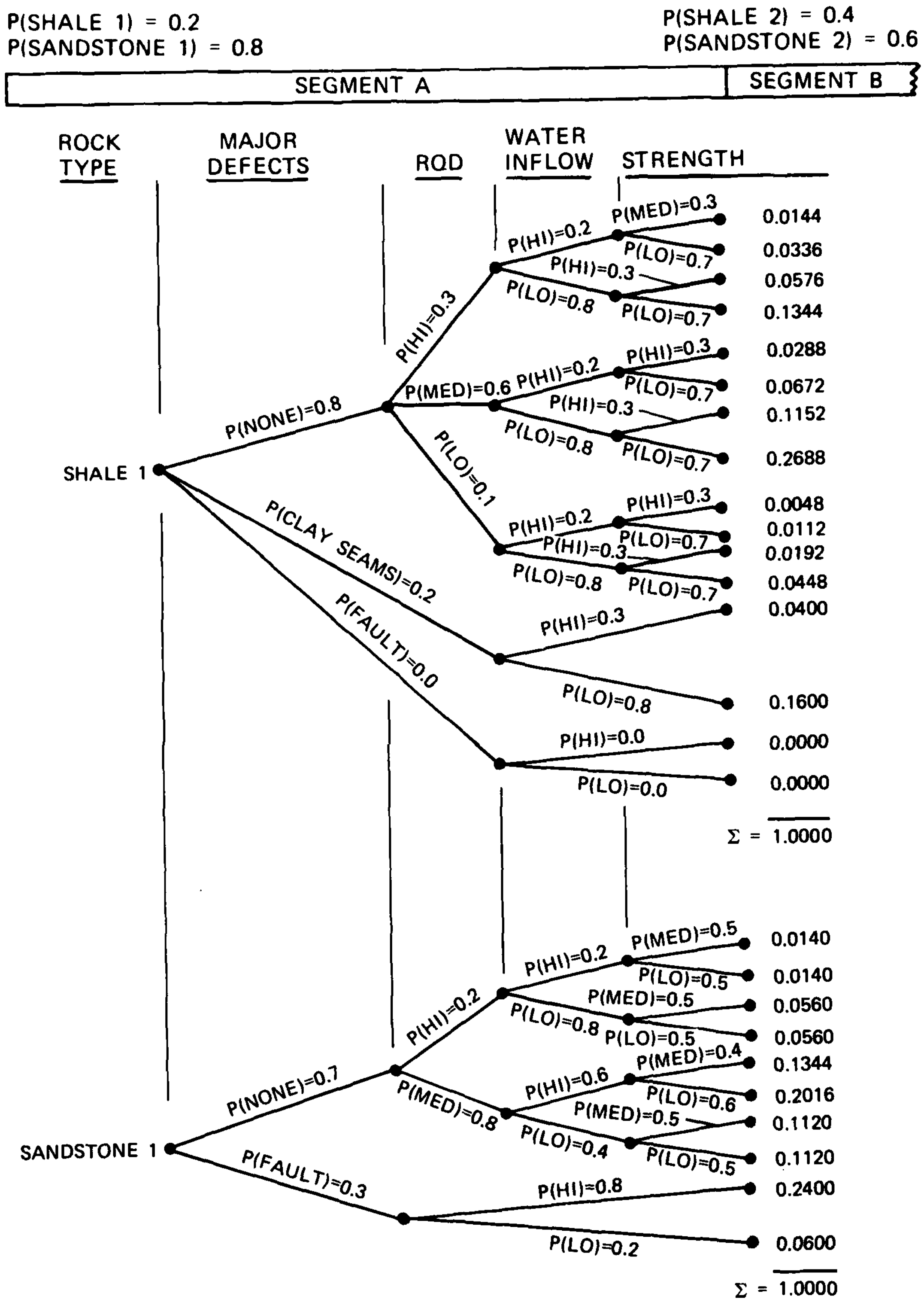

Figure 1. TCM parameter tree

valid must be identified in the input data. The process of defining segment limits and rock units within segments is interdependent. Regardless of the number of rock types possible within a segment, the sum of the probabilities of occurrence of each unit must be 1.0. For the example shown in Figure 1, the probability of encountering shale 1 in segment 1 is set at 0.2 and the probability of encountering sandstone 1 in segment 1 is 0.8. In addition, the sum of the probabilities of the right end nodes of each parameter tree must be 1.0. The extreme right node probabilities of parameter trees are obtained by cumulative multiplication of the probabilities along each continuous branch. For example, the probability of encountering shale 1 in segment 1 with no major defects, medium RQD (30-70 percent), low inflow, and low strength is given by

$$P(\text{Shale 1}) \times P(\text{No Defects}) \times P(\text{Med RQD}) \times P(\text{Low Inflow}) \times P(\text{Low Strength})$$

which for the example in Figure 1 is

$$\begin{aligned} P &= 0.2\ (0.8 \times 0.6 \times 0.8 \times 0.7) \\ &= 0.2\ (0.2688) = 0.0538 \end{aligned}$$

A new parameter tree must be created for each rock unit within the segment. In the simplified example shown, only two rock units were considered within segment 1; the most likely unit was sandstone with a probability of 0.8 and the least likely (P = 0.2) was shale. Thorough guidelines for forming segments and parameter trees are given by Vick (1974), Moavenzadeh (1974b), and Reynoso (1976). The interested reader is referred to Benjamin and Cornell (1970) or Blum and Rosenblatt (1972) for a more comprehensive treatment of probability and statistics for decision making.

45. New tunnel segments must be created when the user wishes to change the set of geological states or associated probabilities of the states. Segments may be independent, partially dependent, or completely dependent. Complete independence is assigned to segments modeled without consideration of rock types assigned in adjacent segments. Complete dependence is assigned to segments whose parameter trees are totally dependent on those of adjacent segments. The most general case, partial

dependency, is modeled using Markov dependency tables. This case would be appropriate for modeling the occurrence of a fault, for example, where the user feels that if the fault is encountered in a given segment, there is an increased (or decreased) likelihood of the fault extending into the next segment. The interested reader is referred to Barucha-Reid (1960) or Stark and Nicholls (1972) for the theoretical development and applications of Markov processes. After assimilating the parameter trees and Markov tables for segment relationships, the geological model produces and stores a user-specified number of profiles to be used by the tunnel simulator to produce estimates.

Construction submodel

46. This component calculates unit times and costs of each construction operation modeled, based on supplied input values of construction variables. Major features and functions of the submodel are:

a. Scheduling procedure - to specify the number and locations of headings and timing of operations at each heading.

b. Model of construction elements - to describe the excavation, support, dewatering, probe drilling, and lining cycles and interactions.

c. Construction method specification - to specify the methods to be used for particular geological conditions and for each heading worked.

d. Construction parameter specification - to input unit costs, times, productivity rates, and other related data.

e. Simulation routines - to compute cycle times and costs for each geological condition considered.

Cycles are calculated for excavation, mucking, muck hauling, muck hoisting, support installation, pumping, grouting, probe drilling, and lining. Aboveground costs are not considered by the simulation routines. When modeling multiple headings, construction operations are assumed to be independent. This assumption is usually acceptable unless alternating faces are worked from the same exit shaft or adit.* The model calculates approximate mobilization time and cost. It does not consider

* The latest version of TCM incorporates provisions for modeling alternating headings more realistically.

permanent pumping, ventilation, architectural finish, or roadways in its cost simulation routines. The construction submodel does not rely on data files for unit costs or cycle times for any tunneling operations. All data must be supplied by the user. The amount of detailed user input is rather large. Much of these data could be assembled only by an experienced estimator team. Owners or planners would quite likely have problems supplying some of the required input. These data are assigned values for worst case, best case, and expected case. In addition, the distribution that describes the data may be normal, beta, or uniform. After all user input has been assimilated, the construction submodel computes cycle time and costs for each construction operation modeled.

Tunnel simulator

47. The tunnel simulator combines the profiles produced by the geological submodel with the calculated cycle times and costs for each geological state and construction method produced by the construction submodel to calculate the total time and cost required to construct the tunnel through each of these profiles. The results are plotted in a scattergram such as Figure 2. It also produces a series of progress reports showing detailed advance of tunnel operations at different times. An optional file can be used to store individual simulations (each simulation constitutes one tunnel estimate). The individual results can be printed out and used in statistical analysis routines to calculate expected cost, standard deviation, etc.

User instructions

48. As mentioned earlier, TCM is a rather large and complex computer program and requires a computer with large storage capacity. Because of its size and the fact that it is written in PL/I, it was considered impractical to adapt it to the WES computer system. The only installation known to the author that currently has an operating version is MIT, and TCM is operational on the IBM 370/168 at MIT. Computers exist within the Corps and with contract vendors that could accommodate the program. However, to convert the program to Fortran IV, the computer language most familiar to noncomputer specialists, would essentially require writing a new program patterned after TCM, which probably would

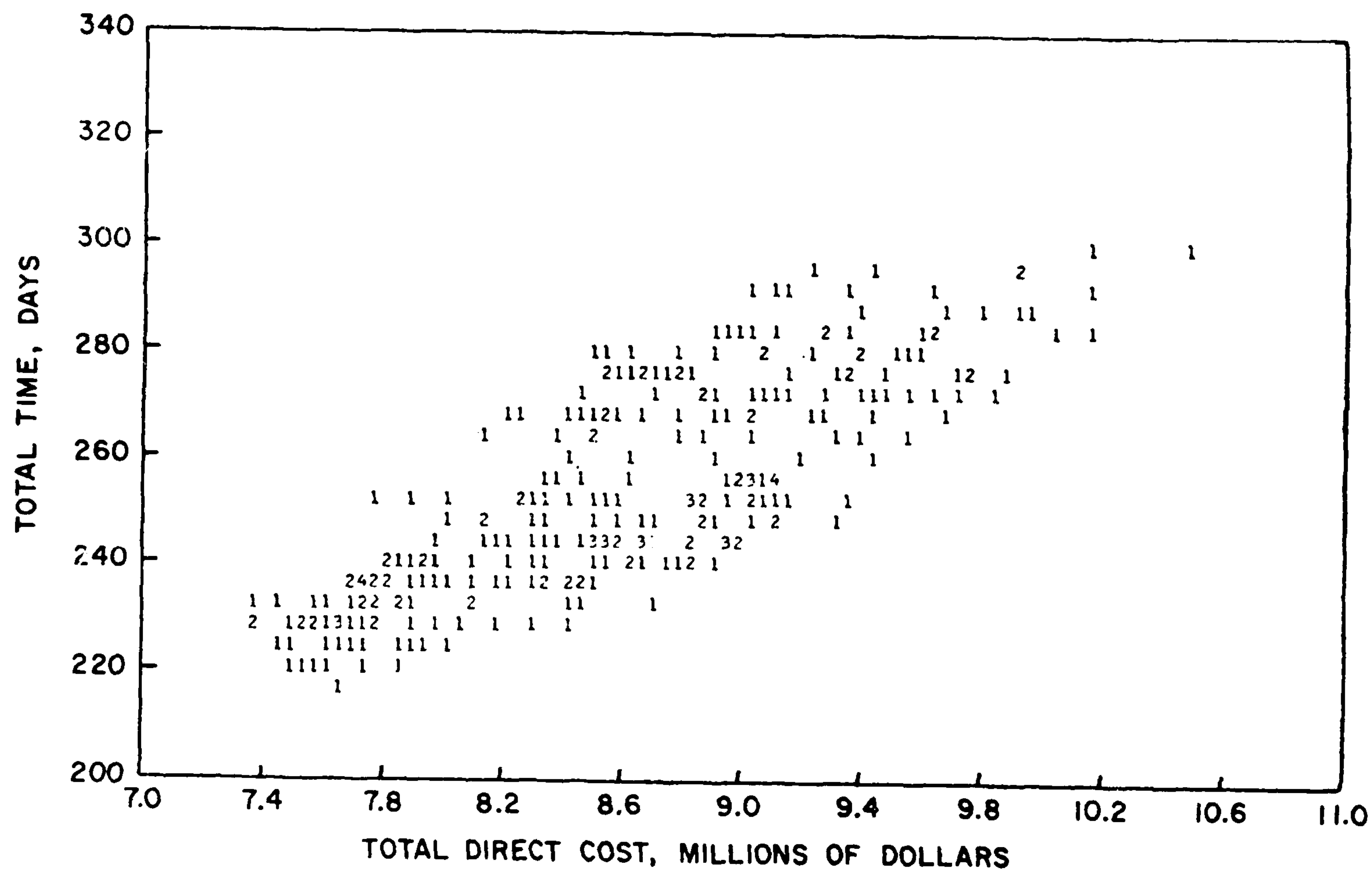

Figure 2. Scattergram: results of 300 tunnel simulations (from Moavenzadeh et al. 1974)

not be as flexible and comprehensive as the MIT version. The interested reader can secure a comprehensive user's manual (Reynoso 1975) from MIT. Therefore, instructions for using TCM are not presented in this report.

Applications

49. The program developers reported the use of TCM to prepare estimates of several tunnels (Minnot 1974 and Wyatt 1974). Normal practice was to perform several hundred simulations for each tunnel to cover all situations. The scattergrams of costs and time were then statistically analyzed to yield the expected cost and time, worst and best cases, etc. A detailed comparison of TCM estimates and actual costs was not presented in the MIT series. However, for the Harold D. Roberts Tunnel in Colorado, estimated advance rates varied significantly from actual rates. These differences were attributed to discrepancies between actual geology and model input describing geology (Wyatt 1974).

TM - Performance/Cost Tunneling Model

50. The performance/cost tunneling model (TM) was developed by General Research Corporation for the Advanced Research Projects Agency/ Bureau of Mines program in rock mechanics and rapid excavation. Its development and application are discussed by Pietrzak et al. (1972) and Hibbard et al. (1971).

General philosophy

51. In general, the program philosophy lies somewhere between COSTUN and TCM. COSTUN employs empirical equations based on regression analysis of previous tunnel jobs to determine support requirements, dewatering requirements, advance rates, etc. (There are provisions for the user to override the calculated values by supplying parameter values he thinks are more appropriate). Also, COSTUN employs a fixed geology model. The TCM program models uncertainty in its geology and construction submodels. All variable parameters affecting tunnel construction must be input by the user. In addition, the user must supply subjective probability of the occurrence of each variable state modeled.

Geology submodel

52. TM employs a user specified geology model (uncertainty is not accounted for) similar to COSTUN, with the added capability of modeling geology in three dimensions or using familiar 2-D profiles. The geology model does not consider soil profiles or mixed face. For each rock stratum, the model generates a file of material properties including density, RQD, abrasiveness, unconfined compressive strength, water inflow, and rock temperature. Parameter values are supplied by the user for each tunnel segment.

Tunneling submodel

53. The tunneling submodel simulates construction operations and conditions. The model can simulate various full-face rock excavation methods, including innovative techniques, but must be supplied with very detailed input to describe all relevant parameters. Soft ground, cut and cover, and mixed face cannot be simulated by TM. Likewise, shafts, portals, adits, and aboveground costs are not considered. Permanent pumping, roadbed or track, permanent lighting, and other architectural finish items are also omitted from consideration. Advance rates are computed using preprogrammed empirical relationships developed from a study of case histories. Construction progress reports are printed during simulation at user-specified time intervals. These status reports could be valuable aids for monitoring progress and costs and correcting problems as they occur. Information printed out includes heading position, elapsed time, average advance rate, availability, and utilization factors for each construction operation (excavation, support, dewatering, etc.).

Cost submodel

54. The cost submodel uses the input unit cost values for labor, materials, and equipment, the calculated quantities, advance rates, support requirements, dewatering and air conditioning requirements, etc., to calculate and tabulate costs accrued for each tunnel increment (measured in time, not distance). Profit and overhead, which are input by the user, are added to the costs. Cost status reports are printed for the same time intervals as the performance reports, including the cost and time of the completed tunnel.

Applications

55. The developers of this model report good correlation of calculated and actual values of advance rate, total time of construction, and cost for the Layout Tunnel. This tunnel, built in 1971-72 as part of the U. S. Bureau of Reclamation (USBUREC) Strawberry Aqueduct System, is approximately 3-1/4 miles long and 13 ft in diameter. It was moled through hard sandstone and conglomerate. The model is well suited for comparison of alternatives, but its use for detailed estimates is hampered because of the large storage requirements and detailed and extensive input data requirements.

TSC/FMA - Transportation Systems Center/Foster Miller Associates Model

56. The Transportation Systems Center/Foster Miller Associates (TSC/FMA) computer model was developed in 1979 through a cooperative effort of the Underground Technology Development Corporation and SKNH Company, under the sponsorship of the Urban Mass Transportation Administration (UMTA), United States Department of Transportation (USDOT). Complete documentation of the development and application of the model is contained in a report by Foster et al. (1979). Copies are available from the National Technical Information Service, Springfield, Virginia.

General philosophy

57. The program is run on a Wang Model 2200 computer. Data files are stored on discs. The model consists of two main data bases and supporting computations. Data Bank 1 contains factors that describe the amount of effort required to accomplish each unit operation. Data Bank 2 contains unit costs of labor, equipment, and materials required. Unit effort data were developed from analysis of 20 soft ground transit tunnels built in the United States in the last 10 years. The model is applicable to soft ground transportation tunnels and stations. Base or reference unit cost data reflect conditions prevailing in Washington, D.C., in January 1976. Costs for other times or regions may be adjusted using inflation factors similar to the method used with COSTUN, or the

actual unit costs may be determined and used in Data Bank 2. Only excavation and lining for soft ground transit tunnels are considered in the present version, although the developers report that it will be revised to make it more comprehensive as data on other operations are developed.

Applications

58. The model has been used on three sections of the Washington Metropolitan Area Transit Authority (WMATA) subway system. Section 1 consisted of 5393 ft of concrete-lined tunnel driven through moderate ground requiring some stabilization, an 800- by 75-ft station, and four vent and fan structures. The section actually analyzed was 2996 ft of tunnel, excavated by a backhoe digger arm under a shield. The actual construction costs were $5,837,000. The FMA estimate was $6,345,000, or 8.7 percent above actual cost. For the tunnel only, actual costs were $4,445,000, and the model estimate was $4,332,000, or 2.5 percent below actual cost.

59. Section 2, consisting of 8820 ft of tunnel, was driven through difficult ground and passed beneath several bridge piers and abutments. Excavation was accomplished by a backhoe digger arm under a shield. Steel segments served as both primary support and final lining. The actual project costs were $33,373,000 for those items considered by the model, which estimated the costs at $31,017,000, or 7.1 percent lower. For tunnel excavation, lining, backfill, and grouting, the actual costs were $25,721,000, and the model estimate was $24,648,000, or 4.2 percent lower.

60. Section 3 comprised 8115 ft of concrete-lined tunnel, an 800- by 75-ft cut-and-cover station, and six vent and fan structures. The section actually analyzed was 3803 ft long. Excavation was accomplished with a wheel excavator through good soft ground. Support was provided by expanded ring beams and wood lagging. The actual cost for the analyzed section was $6,443,000, and the model estimate was $6,731,000, or 4.5 percent higher. For tunnel costs only, the actual cost was $4,603,000, and the model estimate was $5,044,000, or 9.6 percent higher.

61. These results indicate that for its intended applications, the model provides estimates that are within 10 percent of actual costs,

provided there are good definitions of geology, excavation methods, and support requirements.

User instructions

62. Complete instructions for using the TSC/FMA model are available from the Transportation Systems Center, Department of Transportation, Cambridge, Massachusetts. Therefore, instructions are not repeated in this report.

Comparison of Computer Models, Cost Curves, and Manual Estimates

63. The investigation of the steps involved in estimating tunnel costs using all the methods described above clearly indicated that there is no one best method for all purposes. The choice of method must be based on the end use of the estimate. Detailed manual estimates for final design, contract documents, and contractor bids are probably here to stay. Cost curves or unit cost estimates may be useful for preliminary estimates and comparison of alternatives. Computer models may be used to good advantage for preliminary planning estimates, evaluation of alternatives, checks on manual estimates, and monitoring progress. Table 2 presents the relative advantages of the four models investigated during this project. One of the objectives of the project was to develop or adapt cost-estimating aids that planners not intimately familiar with tunneling could use. All things considered, COSTUN meets these criteria better than any of the other models studied. Therefore, it was selected for in-depth analysis, using collected tunnel case histories.

PART III: ANALYSIS OF CASE HISTORIES

64. One of the problems in this study was obtaining case histories of tunnels with sufficient information to: (a) allow a meaningful comparison of the reliability of manually prepared cost estimates with those generated by the computer program COSTUN, (b) allow a meaningful comparison of estimated and as-built costs, and (c) identify the factors responsible for overruns between estimated and as-built costs. After much studying and then discarding of several cases where complete documentation was unavailable, three tunnels were chosen that had good documentation of geology, design, construction methods, and estimates. The following paragraphs present brief descriptions of each tunnel, followed by an analysis of estimated and as-built costs and factors responsible for the differences between the two.

Nast Tunnel

65. Nast Tunnel was the first tunnel in the United States to be driven through granite with a boring machine (Larson 1975). Moles were thought to be unsuitable for hard rock tunnels prior to this job because of high cutter bit replacement costs. Indeed, on this job cutter bit costs amounted to over $1,200,000 on a winning bid price of approximately $6,800,000. Nast Tunnel is a 15,653-ft-long, 10-ft-diam water tunnel that was designed by the USBUREC and built between 1970 and 1973 in Pitkin County, Colorado. On this job contractors were allowed to bid on a drill and blast schedule and an alternative mole-driven tunnel option. Nine bids were received, six on the drill and blast schedule and three on the mole schedule. The winning contractor bid about the same amount on both options. The award was made for the schedule using the boring machine, and a Memorandum of Understanding was executed that permitted the contractor to change from mole driven to drill and blast at his option. Approximately 85 percent of the tunnel was moled; 15 percent was conventionally driven through reaches of poor quality rock.

66. All information used to develop and compare cost estimates of Nast Tunnel was provided by the USBUREC Engineering and Research Center, Denver, Colorado. Their cooperation is gratefully acknowledged. Table 3 summarizes the cost estimates prepared by the engineer, various contractors, and the COSTUN computer model. All identifiable costs not considered by the computer model were subtracted from the total bids so that a meaningful comparison could be made. Engineer estimate 1 and contractor bids 1-6 were for the conventional or drill and blast excavation schedule. Engineer estimate 2 and contractor bids 7-9 were for the mole excavation schedule. Contractor bids 1 and 7 were submitted by the same contractor, and the bid price for either option was about the same. Furthermore, when all schedule items were included, the bid prices were identical for both options. This contractor was awarded the contract, although one other bid, No. 8 in Table 3, was apparently lower. However, when the excluded costs were added back, this bid was higher than the winning bid. The winning bid was approximately 33 percent higher than the engineer estimate for either excavation option. The highest bid was nearly double the engineer estimate. There was a 45 percent spread between the winning and the highest bid.

67. COSTUN estimates 1-9 were prepared using information available at bid time. COSTUN estimate 1 represents the estimated construction cost for the most likely tunneling conditions, using mole excavation when feasible and drill and blast excavation in poor rock zones and near the inlet and outlet portals. The support and lining types and amounts used for this estimate were those called for in the plans and specifications. The total estimated tunnel costs for this run were \$7,089,000, or 5 percent above the winning bid of \$6,763,000 and 38 percent above the engineer estimate. COSTUN estimates 2-9 could be called "what if" estimates, in that the major input factors believed to affect construction costs were individually examined while holding all other variables constant at the expected value. Pessimistic and optimistic values were assigned to each of the major variables for each tunnel segment and reach. Some of these estimates reflected genuine uncertainty while others were used to test the sensitivity of costs to changes in a

specific variable. For example, runs 2 and 3 were made to determine the construction cost impact of varying rock strength. The actual rock strengths were known within reasonable limits from lab tests and empirical correlations, but studies have shown that stand-up time, advance rate, mole cutter bit wear, drill steel life, etc., are at least partially dependent on rock strength, among other things.

68. In run 2, the rock strengths input were 25 percent higher than expected strengths. For most types of structures, an increase in strengths is welcomed, but not necessarily for tunnel excavation. Higher strengths are associated with the harder crystalline rocks that are more abrasive. The results are higher cutter bit wear, more drill steel breakage, and overall slower advance rate, leading to increased costs. For this tunnel, the estimated consequences were nearly $500,000 (6 percent) and 100 working days (10 percent) over the estimate for most likely conditions. Run 3, which used strengths 25 percent lower than expected, resulted in estimated cost and time savings of $450,000 (6 percent) and 102 working days (10 percent) less than the estimate for most likely conditions.

69. The impact of variation in rock quality was assessed in runs 4 and 5. These runs reflected genuine uncertainty in the expected rock joint frequency, joint conditions, and degree of weathering for which the borehole data were lacking. In fact, change order No. 8, which provided for additional payment to the contractor of $767,000, was directly related to the occurrence of a major shear zone approximately 1700 ft long, which had not been detected by surface mapping or borings. The tunnel boring machine had to be moved back and the heading was advanced through this reach by the drill and blast method, using closely spaced heavy steel sets for support. In run 4, pessimistic values of RQD, approximately 33 percent lower than the expected values, were used. Estimated construction time increased 22 percent to 1203 days, or 218 days more than the expected time of 985 days. Estimated costs rose to $8,264,000, or 17 percent above the $7,089,000 expected cost. In run 5, RQD values 33 percent higher than expected were input. The estimated cost reduction was $718,000 (10 percent), while the time was cut 12 percent to 865 days.

70. In runs 6 and 7, the cost/time impact of reducing and increasing, respectively, the lining thickness by 30 percent of the design value was assessed. The specification of lining thickness is of major importance to the cost of a tunnel. The quantity of concrete that must be placed obviously increases for conservative (thicker) lining specifications. Additional cost and time penalties occur because the volume of rock that must be excavated increases proportionately. The larger the tunnel diameter and length, the more serious are the consequences. Compounding this problem is the lack of understanding of interaction between rock load and deformation and transfer of the load to the lining and support.

71. For a reduction of 30 percent in lining thickness (run 6), estimated costs were reduced by $527,000 (7 percent), and construction time was reduced by 30 days (3 percent) over the length of the tunnel. This reduction represents a $33/ft saving over the design lining thickness. A 30 percent increase in lining thickness (run 7) resulted in a 7 percent ($484,000) increase in cost and a 2 percent (24 days) increase in construction time.

72. Computer estimates 8 and 9 were made to study the impact of rock temperature in the tunnel. As expected, the results of these runs indicated that for the range of temperatures expected in Nast Tunnel, there was no effect on cost. In deep tunnels with higher temperatures, the cost of ventilation and air conditioning increases, but for shallow tunnels, such as Nast, there seems to be no effect.

73. The final cost for Nast Tunnel was $7,473,000, including change orders for differing site conditions and other unforeseen problems. This sum excludes those costs not considered by COSTUN, such as access roads, drainage ditches, the Fryingpan Conduit, and the Granite Adit portion of the job. Granite Adit is a 10-ft-diam, 777-ft-long tunnel intersecting Nast Tunnel about 4000 ft from the inlet portal. Its purpose was to convey water from Granite Creek to Nast Tunnel. During construction, it was used as an exit for muck hauling and disposal for the reaches of tunnel adjacent to it. Fryingpan Conduit is a 1500-ft-long conduit constructed of 7-ft-diam precast concrete pipe,

connecting Nast Tunnel at the outlet portal to Boustead Tunnel's inlet portal, which is a diversion tunnel through the Continental Divide.

74. The COSTUN as-built estimate totalled $7,691,000, or 3 percent above the actual cost. The changes made between the COSTUN preconstruction estimate using most likely conditions and the COSTUN as-built estimate included the allowance for the 1700-ft shear zone and a smaller shear zone approximately 300 ft long, both of which caused a change from mole excavation to the drill and blast method. In addition, one segment approximately 4000 ft long that ran under a small lake experienced minor water inflows, but the resulting cost increase was insignificant.

75. Table 4 contains a breakdown of COSTUN estimates 1-9 and the as-built estimate for labor, equipment, and materials components and the totals. Also shown is the total time required for construction of the tunnel for each estimate. Labor was the major cost component for this job and most tunnels, accounting for two thirds of the total for all estimates. Equipment and materials were nearly equal, averaging 16 and 17 percent, respectively, of the totals. Foster et al. (1979) indicate that a breakdown of 40 percent for labor, 40 percent for materials, and 20 percent for equipment is reasonable. Because tunnel jobs vary so widely in nearly all aspects, no significance should be attached to these figures for tunnels in general. The engineer estimates and contractor bids were not itemized for labor, equipment, and materials, so there is no basis for comparison of COSTUN figures except for the totals shown in Table 3. These figures show that the COSTUN best estimate of actual conditions was 5 percent above the winning bid. The COSTUN as-built estimate was 3 percent higher than the actual cost. These figures indicate very good correlation, but they do not give the total picture. The multitude of factors used to arrive at the estimated totals may or may not represent actual conditions. For example, the profit and overhead factors represent a combined 30 percent of the totals in the estimates. The actual profit and overhead, as well as the figures used in the bid, are unknown. Therefore, the reader is cautioned that although the overall accuracy of the estimates looks good, the accuracy of individual factors may not have been as good. The self-cancelling nature of random errors in these factors could still result in a balanced total estimate.

Buckskin Mountains Tunnel

76. Buckskin Mountains Tunnel, a 6.8-mile-long, 22-ft-diam irrigation tunnel, was designed by USBUREC and built near Parker, Arizona, as part of the Central Arizona Project. Prospective bidders were allowed to bid on three alternatives: (a) a 19-ft 6-in.-diam, drill and blast horseshoe-shaped tunnel; (b) a 20-ft-diam, circular-moled tunnel with cast-in-place concrete lining; and (c) a 22-ft-diam, circular-moled tunnel with a precast concrete segmental lining. The award was made for the 22-ft-diam tunnel, and construction began in 1975. The tunnel was holed through in May 1979, but final cleanup has not been completed at the time of this report. A Robbins mole was used for the entire length, except for approximately 100 ft at each portal excavated by drill and blast. The tunnel support and lining consist of 6-in.-thick precast concrete segments, installed just behind the mole. The tunnel was driven through competent andesite, but some blocky conglomerate was encountered that slowed progress. A $6-million changed conditions claim concerning this blocky zone is still pending and may add to its $60-million expected total cost.

77. Information used to develop and compare COSTUN estimates for Buckskin Mountains Tunnel was obtained from three sources: (a) the USBUREC Engineering and Research Center, Denver, Colorado, provided geology reports; (b) the U. S. Army Engineer District, Kansas City, loaned a set of job specifications, including engineer estimates and contractor bids; and (c) the personnel of the resident engineer's office, USBUREC, Parker, Arizona, provided other useful information. Table 5 summarizes the cost estimates prepared by the engineer, various contractors, and the COSTUN computer model. All identifiable costs not considered by the computer model were subtracted from the contractor bids and engineer estimates for the sake of comparison.

78. Engineer estimate 1, COSTUN estimate 1, and contractor bid 1 were for the 19-ft 6-in.-diam horseshoe-shaped tunnel on the drill and blast schedule. The engineer estimate for this option was $53,991,000, as compared with $51,641,000 for the COSTUN estimate and $65,513,000 for

the lone contractor bid on this option. Engineer estimate 2 ($47,441,000), COSTUN estimate 2 ($53,841,000), and contractor bid 2 ($71,208,000) were for the 20-ft-diam moled tunnel option with cast-in-place concrete lining. Both of the above options show a rather wide spread (27 and 50 percent, respectively), although the engineer and COSTUN estimates are within 5 and 13 percent of each other.

79. Engineer estimate 3, contractor bids 3-5, and COSTUN estimates 3-9 are for the 22-ft-diam moled tunnel with precast concrete segmental lining. COSTUN estimate 3 of $59,959,000 represents the estimated cost for the most likely conditions known at bid time, which is 27 percent higher than the engineer estimate of $47,257,000 and 33 percent higher than the winning contractor bid of $44,940,000. The highest bid of $63,493,000 was 41 percent higher than the winning bid, 34 percent higher than the engineer estimate, and 6 percent higher than the COSTUN estimate. The winning bid was 5 percent lower than the engineer estimate. At first glance, the COSTUN estimate seems to be far too high. However, the as-built cost of the tunnel was reported as approximately $60 million, which lends more credence to the COSTUN estimate.

80. COSTUN estimates 4-9 were used to check the cost impact of varying input parameters, one at a time, over a range of values. For an increase of 15 percent over the most likely RQD values (COSTUN estimate 4), the estimated cost was reduced to $52,287,000, or 13 percent below the estimate for most likely conditions. A 15 percent decrease in RQD values in COSTUN estimate 5 produced an expected cost of $75,130,000, or 25 percent higher than the $59,959,000 expected cost for most likely conditions. In COSTUN estimates 6 and 7, the unconfined compressive (UC) strengths were increased and decreased 25 percent, respectively, from the most likely values. The resulting costs were $72,054,000 for a 25 percent increase in UC strengths (20 percent above the $59,959,000 for most likely conditions) and $49,581,000 for a 25 percent decrease in UC strengths (17 percent below the expected cost for most likely conditions). The lining thickness was increased 33 percent in COSTUN estimate 8 over the actual lining thickness used in construction (6 in.) and was increased to 10 in. (67 percent) in COSTUN estimate 9. These runs produced

estimates of $61,373,000, or 2.4 percent above the total cost for the actual lining thickness used, and $62,826,000, or 4.8 percent higher, respectively. The increase in cost per linear foot of tunnel over the actual lining thickness amounted to $39 and $41, respectively, on a base cost of $1670/ft.

81. The as-built cost of Buckskin Mountains Tunnel was reported as $60 million in round figures. The COSTUN estimate representing conditions known at the end of construction totalled $61,474,000, or 2.5 percent above the actual cost. However, as mentioned earlier, a $6-million claim for changed conditions is pending and may add to the total cost. Even if the entire $6 million is awarded to the contractor, the COSTUN estimate would be only 7 percent below total cost. Thus, the COSTUN as-built estimate falls within the range of accuracy of -7 to +2.5 percent. Again, although the overall accuracy of the total cost figures looks good, the accuracy of individual components may not be as good. For example, the engineer estimate for excavation in the tunnel was $29,589,840, while the COSTUN estimate for this work was $38,495,000, or 30 percent higher. This difference is consistent with the overall spread between the engineer and the COSTUN estimate of 27 percent, cited earlier. However, the engineer estimate for furnishing and installing the segmental lining was $16,972,000, while the COSTUN estimate was $17,267,445, or 1.7 percent higher. These component costs compare favorably, but the 27 percent spread between the estimated totals is not reflected. Obviously, the difference had to be greater among the remaining component costs in order for the total 27 percent difference to be achieved.

82. Table 6 presents the breakdown of estimated costs for labor, equipment, and materials and the estimated time for construction of the tunnel for COSTUN estimates 1-9 and the COSTUN as-built estimate. The average cost of labor amounted to 60 percent of the total, while the equipment accounted for 22 percent and materials accounted for the remaining 18 percent for the 10 estimates.

83. The estimated time required to complete the tunnel ranged from 2475 to 4095 days for the three options under most likely conditions.

These figures contrast sharply with the allotted contract time of 1800 days, which the contractor met. The reasons for this discrepancy in estimated times could not be determined. Again, this case shows that even when the estimated totals agree closely, there can still be large differences in some factors or components. It is interesting to note that the least expensive alternative according to the COSTUN estimates was the 19-ft 6-in.-diam, horseshoe-shaped drill and blast option at $51,641,000, while the 20-ft-diam, circular-moled tunnel was second at $53,841,000 and the 22-ft-diam moled tunnel was the most expensive at $59,959,000. The engineer estimates are exactly reversed, with the 22-ft-diam tunnel the least expensive and the 19-ft 6-in.-diam tunnel the most expensive tunnel option.

Park River Tunnel

84. Park River Tunnel is a 22-ft-finished-diam, 9095-ft-long Corps of Engineers tunnel, that is located approximately 150 ft below street level in Hartford, Connecticut, and was designed to convey flood flows of the Park River to the Connecticut River. It passes through sandstone and shale, most of which is of good quality. One shear zone approximately 270 ft long was encountered, as predicted by exploratory borings. Prospective bidders were allowed to bid three alternatives for driving the tunnel: drill and blast excavation with a cast-in-place concrete lining, mole excavation with cast-in-place concrete lining, and mole excavation with a precast segmental crete lining. The award was made for the mole-driven tunnel with precast segmental concrete lining. Construction began in 1977, and the tunnel was holed through in July 1980. Approximately 150 ft near the outlet portal was excavated by drill and blast for a staging area for the mole, as well as approximately 270 ft of shear zone.

85. Information used to develop and compare COSTUN estimates for Park River Tunnel was furnished by personnel of the U. S. Army Engineer Division, New England. Table 7 summarizes the cost estimates and bids. Table 8 presents a breakdown of the various COSTUN estimates for labor,

equipment, materials, and time required to build the tunnel. In addition to the data used for comparison on the two tunnels previously discussed, the estimated costs are also displayed for the two shafts associated with this project (Table 7). As with the other tunnels, all identifiable costs not considered by the COSTUN model were subtracted from the engineer estimates and contractor bids for a meaningful comparison.

86. Engineer estimate 1, contractor bid 1, and COSTUN estimate 10 are for the drill and blast option. The engineer estimate for tunnel construction was $20,916,000, as compared with the contractor bid of $24,885,000 and the COSTUN estimate of $19,476,000. For the inlet shaft, the engineer estimate was $770,000, the COSTUN estimate $1,971,000, and the contractor bid $1,800,000; for the outlet shaft, the engineer estimate was $1,100,000, the COSTUN estimate $1,981,000, and the contractor bid $3,000,000. The total project was estimated to cost $22,786,000 by the engineer, $23,428,000 by the COSTUN model, and $29,685,000 by the contractor (a spread of 30 percent).

87. Engineer estimate 2, contractor bid 2, and COSTUN estimate 11 are for the mole excavation schedule with cast-in-place lining. The engineer estimates and COSTUN estimates for the inlet and outlet shafts were unchanged, while the contractor bids were $3,500,000 for the inlet and $3,000,000 for the outlet shaft. The tunnel construction was estimated at $17,977,000 by the engineer, and $16,785,000 by COSTUN, as compared with the contractor bid of $14,096,000. Since the contractor bids for the shafts were much higher than either estimate and the bid for tunnel construction was much lower, this imbalance might have been a strategy to increase early cash flow. The estimates and bids for the total project were $19,847,000 by the engineer, $20,737,000 by the COSTUN model, and $20,596,000 by the contractor (a spread of just 4.5 percent).

88. The contractor awarded the job on the mole excavation schedule with precast lining bid $17,329,000 on the project (contractor bid 3). The bid was 3.7 percent lower than engineer estimate 3 of $17,993,000 and 5.8 percent lower than COSTUN estimate 1 of $18,405,000. Again, the

contractor bids for tunnel, inlet, and outlet shafts appear to be unbalanced. For the outlet shaft, from which tunnel excavation proceeded, the contractor bid was $4,000,000, while the engineer and COSTUN estimates were $1,100,000 and $1,981,000, respectively. This trend is apparent in every contractor bid on the project, so a comparison of the shafts and tunnel items separately is not meaningful. Only the total project estimates are compared. The next lowest bid of $17,360,000 was 3.5 percent lower than the engineer estimate. The highest bid of $50,310,000 was 280 percent of the engineer estimate. The bid spread was nearly $33,000,000, almost double the winning bid.

89. COSTUN estimates 2-9 were made to test the cost impact of varying rock properties and design lining thicknesses in the tunnel. Shaft properties and costs were held constant. In runs 2 and 3, the RQD values were increased 15 and 30 percent, respectively, over the most likely values. For the 15 percent increase in RQD, the estimated cost of the tunnel decreased to $13,555,000, or 6.2 percent lower than the $14,453,000 expected cost. The 30 percent increase in RQD resulted in a calculated 9.7 percent reduction to $13,055,000. Estimated time savings were 34 days (5.6 percent) in run 2 and 53 days (8.7 percent) in run 3. RQD values were decreased in runs 4 and 5 by 15 percent and 30 percent, respectively. The resulting increases in costs were 9.7 percent to $15,851,000 for the 15 percent decrease in RQD and 34.3 percent to $19,406,000 for the 30 percent decrease. Estimated time penalties were 53 days (8.7 percent) in run 4 and 186 days (30.4 percent) in run 5. In runs 6 and 7, the UC strengths were increased and decreased by 15 percent, respectively. Run 6 produced an estimated cost of $15,543,000, or 7.5 percent higher than the expected cost, while the 15 percent decrease in UC strengths in run 7 resulted in a 7.5 percent decrease in cost to $13,360,000. The estimated time penalty for the 15 percent increase in UC strengths was 40 days (6.5 percent) in run 6, and the estimated time savings attributed to a 15 percent reduction in UC strengths was 39 days (6.4 percent) in run 7.

90. Runs 8 and 9 were made to assess the cost impact of increasing the thickness of the precast concrete segments from 9 to 12 in.

in run 8 and to 15 in. in run 9, amounting to increases of 33 percent and 67 percent, respectively, over the design value of 9 in. The cost penalty was $650,000, or 4.5 percent, for the 12-in. liner and $1,390,000, or 9.6 percent, for the 15-in. liner. The time penalties were 7 days in run 8 (1 percent) and 13 days (2 percent) in run 9 over the expected time of 611 days for the design lining thickness.

91. The COSTUN as-built estimate is identical with the estimate for most likely conditions known at bid time. There were no big surprises in constructing this tunnel, except for some difficulties encountered during construction of the outlet shaft. Because the tunnel has only recently been completed, final as-built costs were not available but are expected to be around $23,000,000. If this estimate is correct, the COSTUN and engineer estimates are 20 and 22 percent, respectively, below the final costs.

92. Table 8 presents a breakdown of COSTUN estimates for labor, equipment, materials, and time required to build Park River Tunnel. Labor costs accounted for approximately 65 percent, equipment 19 percent, and materials 16 percent of the estimated total cost.

PART IV: SUMMARY AND CONCLUSIONS

92. The two basic methods for preparing tunnel estimates are: (a) a simulation of actual construction operations in which amounts and types of equipment and materials needed are estimated, crew productivity rates are estimated, the rates of material and labor usage and tunnel advance are set down, and a total estimated cost is computed; and (b) a comparison with similar tunnels in which the unit costs of major construction components, such as excavation, muck hauling, support and lining, and pumping are determined and applied, with or without adjustments for inflation and other factors to the present tunnel, for which the quantities of each component have been computed. Either of these methods may be performed manually or with a computer. The first approach, actual simulation, is more difficult, time-consuming, and accurate. The second approach, the unit cost method, is much easier to use and gives fair results, especially for preliminary estimates or comparison of alternatives.

93. Over the past decade, several computer models have been developed for estimating tunnel costs. The USDOT has provided the primary support for these efforts, and consequently, most of the models were developed for transportation tunnels (railroad, motor vehicle, and rapid transit).

94. Of the four computer models investigated, COSTUN satisfied more completely program objectives for a flexible, easy to use model that can be used by persons lacking an extensive background in tunneling and cost estimating. It has a wide range of applications, including rock, soft ground, and cut-and-cover tunnels, and considers various combinations of conditions and tunnel-driving methods. It also has several well-recognized shortcomings; e.g., aboveground costs are not considered, risk and uncertainty are not treated explicitly, cost equations are based on average costs for tunnels in Chicago in 1969, and method and equipment selection is based on standard practice (circa 1970).

95. Manual estimates and bid preparation will continue as the "tried and true" method for making final estimates. Computer models are

best suited for preliminary estimates, evaluation of alternatives, and checks on manual estimates.

96. The COSTUN model was evaluated using three completed tunnels for which good documentation of geology, construction methods, design, and cost data were available. All three tunnels were driven through rock, and consequently, the model's reliability for estimating costs of soft ground and cut-and-cover tunnels was not verified. For two of the three rock tunnels, COSTUN estimates were within 6 percent of the winning contractor bids and within 7 percent of the actual costs. These figures indicate very good overall accuracy of the model for rock tunnels. However, the accuracy of individual component costs estimated by COSTUN may vary over a wider range. It is difficult to test the validity of these component estimates for two reasons:

- a. Contractor bids are often unbalanced to improve early cash flow. Therefore, construction costs may be overestimated for components used during the early stages of the project and underestimated for components used during latter stages.
- b. Final, as-built costs are usually reported as a lump sum or with only limited itemization, precluding an item by item comparison.

97. For the three tunnels studied, a variation in rock UC strengths of ± 25 percent resulted in estimated cost savings of 6 to 17 percent for a 25 percent reduction in strengths and estimated cost increases of 6 to 20 percent for a 25 percent increase in strengths. The cost impact from a variation in strengths probably depends on the expected strengths more than any other factor. For example, if very low strengths were expected, an increase in strengths might result in a decrease in costs; however, for the tunnels studied, which were built in rock with moderate to high expected strengths, the reverse was true.

98. The estimated cost impact of varying RQD over a ± 33 percent range was a 17 to 24 percent increase in cost for a 33 percent decrease in RQD and about a 10 percent decrease in cost for a 33 percent increase in RQD. Again the cost impact probably depends on the expected RQD values more than any other factor. For example, if the expected RQD values were low, a 33 percent decrease might make tunnel excavation much more

expensive than the impact of a 33 percent reduction in high RQD values for another tunnel.

99. The savings that can be achieved through less conservative lining thickness can be quite significant. For example, 3 in. added to the precast concrete segments specified for the 22-ft-diam Park River Tunnel would have added an estimated $650,000 to the cost, or about $72/ft of tunnel. Similar effects were observed in estimates for the other two tunnels, though to a proportionally lesser scale in the 10-ft-diam Nast Tunnel.

100. In slopes and foundations, back analyses can provide knowledge of the actual strengths at failure and yield valuable data for future designs. However, with tunnels there is little historical perspective for altering design methods. Tunnel failures are rare; many have been in service for over 100 years. We know what has been successful in the past, but we do not know how conservative our empirical designs are. Much research has been and is being directed toward this problem. Tunnel experts generally admit that currently available analytical methods outstrip our ability to provide reliable input values for the variables needed for solution. Hopefully, this continued effort will lead to better understanding and more economical designs for support and lining.

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Table 1

Explanation of Typical Geological Parameters
Used to Form Parameter Trees

(TCM)

Item	Explanation
1. Rock Type	Left end node. One parameter tree must be created for each geological unit or rock type to be modeled. Rock type or lithology is used mainly to categorize engineering properties of materials. Main effect on tunneling is rate of drill bit or cutter wear associated with different rock types.
2. Major Defects	First branch of parameter tree. Describes faults (RQD = 0 by definition), clay seams, or for limestone and dolomites, solution cavities.
3. Jointing, RQD	Second branch of parameter tree. Expressed as high (70-100), medium (30-70), or low (0-30) to describe relative condition of rock. Helps in prediction of tunnel support requirements.
4. Foliation	Third branch of tree. Used for metamorphic units. When used for sedimentary rocks, refers to bedding.
5. Gas	Fourth branch of tree. Probabilities assigned to existence or nonexistence of gas. No quantitative estimate is made.
6. Water Inflow	Fifth branch of tree. Probabilities assigned to high and low inflow; no numerical values assigned to inflow rate. May be dependent on jointing and defects to some extent.
7. Compressive Strength	Sixth branch of tree. Probabilities of strength being very high (>32000 psi), high (16000-32000 psi), medium (8000-16000), or low (0-8000) are assigned. Used to assist evaluation of bit and cutter wear, advance rates, blast weights and spacings, and support requirements.

Table 2

Comparison of Computer Models

	COSTUN	TCM	TM	TSC/FHA
Applications:	-Tunnels and shafts -Circular, horseshoe, basket-handle, or cut-and-cover box -Finished cross sections from 10 to 40 ft -Rock, soft ground, cut and cover -Excavation by mole, drill and blast; shield w/ripper, mole, or hand except in soft ground	-Tunnels, shafts, adits, caverns -Any shape, size -Rock only -Any excavation method	-Tunnels only -Any shape, size -Rock only -Full-face excavation by mole or drill and blast	-Soft ground only -Transit tunnels and stations -Excavation and lining only
Operation:	-Fortran IV, Honeywell GE635, Univac/108	-PL/1, IBM Machine Language I, IBM 370/168		-Wang 2200, data storage on discs
Philosophy:	-Preprogrammed standard designs keyed to geological input data for support, lining, dewatering, ventilation, etc. -Advance rate, other calculations based on empirical equations -Computed values may be overridden by user-supplied values for advance rate, lining thickness, stabilization methods, etc. -Uses fixed, user-input geology profile -Most representative of models studied to actual estimating procedures used in industry by owners and engineers -User need not be tunnel expert -Profit, overhead, adjustments for inflation of costs are input by user -Considers any geology -Alternatives can be evaluated -Cost adjustment factors used for labor, materials, equipment, and regional productivity differences	-Probabilistic geology model. User defines parameters to describe each rock unit, with associated probabilities of occurrence -All factors affecting tunnel construction must be input by user. Requires very detailed input. Model has no design capability -Breaks costs down to cycle level of operations -Tunnel simulator models uncertainty in construction operations -Very flexible but requires user with extensive background in tunneling, estimating, and statistical modeling -Contingency costs not considered. Modeling of uncertainty replaces it -Statistical inferences of best case, worst case, and expected cost and time, standard deviation, etc., can be easily made	-User input fixed 2-D or 3-D geology file -Very detailed input for construction method, equipment, crew, etc. -Advance rate calculated by model -Quantities and costs of all construction inputs calculated on per foot basis; user supplies unit cost of materials, labor, and equipment	-Program consists of 2 main data bases -Data Bank 1 describes units *of effort required* for each construction operation modeled -Data Bank 2 is a unit cost file, based on Washington, D. C., costs for 1976 -Data Banks were based on analysis of 20 tunnels built in United States in last 10 years -Adjustments may be made to Data Banks for inflation, regional differences, etc. -User input includes geometry, geology, location, time, selection of construction method, support and lining method and type, muck removal method, work week, number of bidders and site preparation requirements
Output:	-Calculated tunnel and shaft data cost and time summaries	-Progress reports of resources used versus time and progress -Scattergram of cost versus time. Each plotted point represents one tunnel estimate -Optional cost/time summaries for user-selected profiles	-Progress reports and cost reports at user-specified time intervals, including time and cost of completed tunnel	-List of input data, and detailed cost and time summaries for modeled construction operations and direct, indirect, and total project costs -Revisions are planned to take account of legal costs, financing, environmental issues, change orders, insurance, mitigation *costs, etc., as well* as more comprehensive treatment of tunnel construction operations and conditions
Advantages/ Disadvantages:	-Rather simplistic parametric relationships between geology and support design -Based on static technology/costs -Aboveground costs not considered -No treatment of uncertainty -Unsuitable for small projects	-Very detailed input data requirements -Very large storage and computer time requirements -User must have in-depth knowledge of tunneling, estimating, probability, and statistics -Aboveground costs not considered -Validity of subjective probability subject to question -Results difficult to interpret -Only the reasonableness, rather than the accuracy, of solutions can be checked. User must thoroughly verify input data	-Very detailed input requirements -User must have in-depth knowledge of tunnel estimating -Aboveground costs not considered -Limited applications. Soft ground, cut and cover, heading and bench, etc., not considered	-Limited application. Considers only soft ground tunnels and stations. Can be used to advantage for comparison of alternatives

Table 3

Nast Tunnel Cost Estimates

Owner: USBUREC
Built: 1970-1973
Length: Design length - 15,653 ft; as-built length - 15,740 ft.
Diameter: Finished - 10 ft
Shape: Circular and horseshoe
General geology: Competent granite, porphyry, some crushed zones

Construction Estimates

Estimate No.	Total Cost millions $	Cost, $/ft
Engineer 1	5.103	326
Contractor 1	6.814	435
Contractor 2	7.238	462
Contractor 3	8.156	521
Contractor 4	7.983	510
Contractor 5	8.355	534
Contractor 6	8.381	535
Contractor 7	6.763	432
Contractor 8	6.568	420
Contractor 9	9.904	633
Engineer 2	5.134	328
COSTUN 1	7.089	453
COSTUN 2	7.535	481
COSTUN 3	6.640	424
COSTUN 4	8.264	528
COSTUN 5	6.371	407
COSTUN 6	6.562	419
COSTUN 7	7.573	484
COSTUN 8	7.089	453
COSTUN 9	7.089	453
As-built Cost	7.473	477
COSTUN (As-built)	7.691	491

Comments

1. Engineer estimate 1 and Contractor bids 1-6 are for the drill and blast excavation schedule
2. Engineer estimate 2 and Contractor bids 7-9 are for the mole excavation schedule
3. COSTUN estimates are for mole excavation in good quality rock and conventional excavation in poor quality rock
4. In all estimates, costs not considered by COSTUN have been subtracted from the manual estimates for sake of comparison
5. Contractor bids 1 and 7 are from same company, drill and blast and mole schedules, respectively. This company was awarded contract with option of using either excavation method as necessary
6. COSTUN estimate 1 represents estimated costs for most likely conditions. COSTUN estimates 2-7 are for possible variations in conditions encountered, or for sensitivity analysis
7. As-built costs include costs of relevant change orders
8. COSTUN as-built estimate includes costs of 87 ft of additional tunneling, which resulted from improper alignment of mole

Table 4

Nast Tunnel COSTUN Estimates

Description	Tunnel Cost, millions $ Labor	Equipment	Materials	Total	Total Constr. Time, days
COSTUN 1 Best estimate of expected conditions	4.738	1.118	1.233	7.089	985
COSTUN 2 Input rock strengths 25% higher than expected strengths	5.094	1.165	1.276	7.535	1084
COSTUN 3 Input rock strengths 25% lower than expected strengths	4.385	1.059	1.196	6.640	883
COSTUN 4 Input RQD 33% lower than expected RQD	5.609	1.279	1.376	8.264	1203
COSTUN 5 Input RQD 33% higher than expected RQD	4.260	0.986	1.125	6.371	865
COSTUN 6 Reduced lining thickness from 18.5" to 12" in segs. 1, 4, 9, 11, 12 and from 14" to 10" in segs. 3, 5, 6, 7, 8, 13 (29 to 33% decrease)	4.546	1.041	0.975	6.562	955
COSTUN 7 Increased lining thickness from 18.5" to 24" in segs. 1, 4, 9, 11, 12 and from 14" to 18" in segs. 3, 5, 6, 7, 8, 10, 13 (29% increase)	4.913	1.168	1.492	7.573	1009
COSTUN 8 Decreased rock temp	4.738	1.118	1.233	7.089	985
COSTUN 9 Increased rock temp	4.738	1.118	1.233	7.089	985
As-built Cost	NA	NA	NA	7.474	1123*
COSTUN (As-built)	5.252	1.129	1.310	7.691	1079

* The number of days required for construction of the tunnel, Granite Adit, Fryingpan Conduit, and other items. No breakdown was available for the tunnel or for the number of crews working simultaneously.

Table 5

Buckskin Mountains Tunnel Estimates

Owner: USBUREC
Built: 1975-1980
Length: 35,910 ft

Diameter: Finished - 22 ft
General geology: Complex volcanic rocks
Location: Near Parker, Arizona

Estimate No.	Total Cost millions $	Cost, $/ft
Engineer 1	53.991	1504
Contractor 1	65.513	1824
Engineer 2	47.441	1321
Contractor 2	71.208	1983
Engineer 3	47.257	1316
Contractor 3	44.940	1251
Contractor 4	50.915	1418
Contractor 5	63.493	1768
COSTUN 1	51.641	1438
COSTUN 2	53.841	1499
COSTUN 3	59.959	1670
COSTUN 4	52.287	1456
COSTUN 5	75.130	2092
COSTUN 6	72.054	2007
COSTUN 7	49.581	1381
COSTUN 8	61.373	1709
COSTUN 9	62.826	1750
As-built Cost	60.0	1671
COSTUN (As-built)	61.474	1712

Comments

1. Engineer estimate 1 and contractor bid 1 for 19-ft 6-in.-diam horseshoe-shaped tunnel, excavated by drill and blast, with cast-in-place concrete lining
2. Engineer estimate 2 and contractor bid 2 for 20-ft-diam, circular-moled tunnel with cast-in-place concrete lining
3. Engineer estimate 3 and contractor bids 3-5 for 22-ft-diam, circular-moled tunnel with precast concrete segmental lining
4. Contractor bid 3 awarded the contract
5. COSTUN estimate 1 for 19-ft 6-in.-diam drill and blast tunnel
6. COSTUN estimate 2 for 20-ft-diam moled tunnel
7. COSTUN estimates 3-9 for 22-ft-diam moled tunnel with precast concrete segmental lining
8. COSTUN estimates 1-3 for most likely conditions known at bid time
9. COSTUN estimate 4 - RQD increased 15 percent
10. COSTUN estimate 5 - RQD decreased 15 percent
11. COSTUN estimate 6 - UC strengths increased 25 percent
12. COSTUN estimate 7 - UC strengths decreased 25 percent
13. COSTUN estimate 8 - lining thickness increased 33 percent
14. COSTUN estimate 9 - lining thickness increased 67 percent
15. As-built cost does not include pending $6-million claim
16. In all manual estimates, costs not considered by COSTUN have been excluded for sake of comparison

Table 6

Buckskin Mountains Tunnel

COSTUN Estimates

Estimate No.	Tunnel Cost, millions $ Labor	Equipment	Materials	Total	Total Construction Time, days	Comments
COSTUN 1	28.878	11.006	11.757	51.641	2475	Drill and blast excavation - 19-ft 6-in.-diam, horseshoe-shaped tunnel
COSTUN 2	29.875	12.871	11.095	53.841	4517	Mole excavation - 20-ft-diam tunnel with cast-in-place lining
COSTUN 3	36.413	13.303	10.243	59.959	4095	Base run - 22-ft-diam moled tunnel with precast concrete segmental lining
COSTUN 4	30.937	11.625	9.725	52.287	3376	Mole excavation - 22-ft-diam tunnel; RQD increased 15 percent
COSTUN 5	47.033	16.905	11.191	75.130	5444	Same to; RQD decreased 15 percent
COSTUN 6	44.224	15.853	11.977	72.054	5088	Same to; UC increased 25 percent
COSTUN 7	29.393	11.691	8.497	49.581	3106	Same to; UC decreased 25 percent
COSTUN 8	37.149	13.688	10.536	61.373	4153	Same to; lining thickness increased 33 percent (from 6-8 in.)
COSTUN 9	37.898	14.085	10.843	62.826	4212	Same to; lining thickness increased 67 percent (from 6-10 in.)
COSTUN (As-built)	37.286	13.638	10.550	61.474	4204	

Table 7

Park River Tunnel Estimates

Owner: U. S. Army Corps of Engineers
Built: 1978-1980
Length: 9090 ft
Diameter: Finished - 22 ft
General geology: Sedimentary deposits, shale and sandstone
Location: Hartford, Connecticut

Estimate No.	Total Cost, millions $ Tunnel	Inlet Shaft	Outlet Shaft	Total Project	Cost $/ft Tunnel
Engineer 1	20.916	0.770	1.100	22.786	2301
Contractor 1	24.885	1.800	3.000	29.685	2738
COSTUN 10	19.476	1.971	1.981	23.428	2143
Engineer 2	17.977	0.770	1.100	19.847	1978
Contractor 2	14.096	3.500	3.000	20.596	1551
COSTUN 11	16.785	1.971	1.981	20.737	1847
Engineer 3	16.123	0.770	1.100	17.993	1774
Contractor 3	11.829	1.500	4.000	17.329	1301
Contractor 4	14.760	1.100	1.500	17.360	1624
Contractor 5	15.111	1.500	4.000	20.611	1662
Contractor 6	14.293	3.500	3.000	20.793	1572
Contractor 7	18.270	1.050	3.400	22.720	2010
Contractor 8	17.689	1.000	2.600	21.289	1946
Contractor 9	20.351	1.800	3.000	25.151	2239
Contractor 10	45.310	2.500	2.500	50.310	4985
COSTUN 1	14.453	1.971	1.981	18.405	1590
COSTUN 2	13.555	1.971	1.981	17.507	1491
COSTUN 3	13.055	1.971	1.981	17.007	1436
COSTUN 4	15.851	1.971	1.981	19.803	1744
COSTUN 5	19.406	1.971	1.981	23.358	2135
COSTUN 6	15.543	1.971	1.981	19.495	1710
COSTUN 7	13.360	1.971	1.981	17.312	1470
COSTUN 8	15.103	1.971	1.981	19.055	1661
COSTUN 9	15.843	1.971	1.981	19.795	1743
As-built Cost					
COSTUN (As-built)	14.453	1.971	1.981	18.405	1590

Comments

1. Engineer estimate 1, COSTUN estimate 10, and contractor bid 1 were for the drill and blast excavation schedule with cast-in-place concrete lining
2. Engineer estimate 2, COSTUN estimate 11, and contractor bid 2 were for the mole excavation schedule with cast-in-place concrete lining
3. Engineer estimate 3, contractor bids 3-10, and COSTUN estimates 1-9 were for the mole excavation schedule with precast concrete segmental lining
4. COSTUN estimate 1 represented costs for most likely conditions known at bid time
5. COSTUN estimate 2 increased RQD 15 percent
6. COSTUN estimate 3 increased RQD 30 percent
7. COSTUN estimate 4 decreased RQD 15 percent
8. COSTUN estimate 5 decreased RQD 30 percent
9. COSTUN estimate 6 increased UC strengths 15 percent
10. COSTUN estimate 7 decreased UC strengths 15 percent
11. COSTUN estimate 8 increased lining thickness 33 percent
12. COSTUN estimate 9 increased lining thickness 67 percent
13. In all manual estimates, costs not considered by COSTUN have been subtracted for sake of comparison

Table 8

Park River Tunnel COSTUN Estimates

Estimate No.	Project Cost, millions $ Labor	Equipment	Materials	Total	Total Construction Time, days	Comments
COSTUN 1	11.907	3.559	2.939	18.405	611	Base run
COSTUN 2	11.259	3.363	2.885	17.507	577	RQD increased 15 percent
COSTUN 3	10.897	3.260	2.850	17.007	558	RQD increased 30 percent
COSTUN 4	12.925	3.859	3.019	19.803	664	RQD decreased 15 percent
COSTUN 5	15.506	4.635	3.217	23.358	797	RQD decreased 30 percent
COSTUN 6	12.637	3.772	3.086	19.495	651	UC strength increased 15 percent
COSTUN 7	11.177	3.344	2.791	17.312	572	UC strength decreased 15 percent
COSTUN 8	12.240	3.724	3.091	19.055	618	Lining thickness increased 33 percent
COSTUN 9	12.617	3.924	3.254	19.795	624	Lining thickness increased 67 percent
COSTUN 10	15.387	3.716	4.325	23.428	699	Drill and blast option
COSTUN 11	14.442	3.462	2.833	20.737	671	Mole option with cast-in-place lining
COSTUN (As-built)	11.907	3.559	2.939	18.405	611	

APPENDIX A: USER'S GUIDE FOR PROGRAM COSTUN

Introduction

1. Documentation for the computer program COSTUN for estimating tunnel costs is presented in this appendix and includes the introduction, input data, program execution and printer output, and program listing.

2. COSTUN is available in batch mode on the WES Honeywell GE635 computer. It has been run on a Univac 1108 at the New England Division (NED) Corps Office. The program is too large for the WES Tymeshare System. The mainline program COSTUN reads the project title, profit and overhead margins, and beginning project stationing. After these data are read, a series of calls to the various subroutines is initiated. The first subroutine called is INPUT, which reads the general project information, elevations of nodal points, and specific values of all input data for each tunnel segment, tunnel reach, shaft segment, and shaft. The computer performs an extensive check of all input data, and error statements are printed out for mistakes or incompatible data. If errors are encountered that would result in inaccurate solutions, a "Fatal Error" message is printed. Less serious errors are indicated by "Warning" messages. The next subroutine called by the mainline program is SFTSET, which calculates shaft geometry. LENGTH is then called to calculate shaft lengths, hoisting heights, tunnel slopes, and lengths. After these calculations have been made, the input data are printed out by subroutine INOUT under headings "Tunnel Input Data" and "Shaft Input Data." Subsequent subroutines calculate excavated dimensions, spoil quantities, advance rates, pumping heights and quantities, and a host of other factors necessary for a complete estimate. These subroutines and their functions are listed and described by comment cards in the program listing and in the documentation report.

Input Data

3. Input data must be entered on the file cards, with all data right-justified within formats. The job control cards are placed at the front of the deck and then followed by:

Item 1. Title cards. All 10 must be included, even if blank. Any alphanumeric data may be entered in columns 1-64.

Item 2. Printout options (one card). Enter code 0 or leave blank to print all input data, 1 in column 1 to suppress nodal points, 1 in column 2 to suppress tunnel input data, 1 in column 3 to suppress shaft input data, 1 in column 4 to suppress calculated tunnel data, 1 in column 5 to suppress calculated shaft data, 1 in column 6 to suppress tunnel segment and reach costs, 1 in column 7 to suppress shaft segment and shaft costs, 1 in column 8 to suppress tunnel reach cost summary, and 1 in column 9 to suppress shaft cost summary.

Item 3. Profit and overhead margins and beginning of project stationing (one card). Columns 1-10 contain profit margin in percent, columns 11-20 overhead margin in percent, and columns 21-30 beginning project stationing, any positive or negative number between ± 10,000. As an example, enter 4059.6; not 40 + 59.6.

Item 4. Nodal point elevations. Use one card per nodal point. Place nodal point number in columns 2-5. Place nodal point elevations in columns 11-20. Nodal points are used to designate the ground surface elevation at each shaft or portal and the ends of shaft and tunnel segments. Tunnel segment elevations should be referenced to center-line elevations and to ground surface for cut and cover.

Item 5. Data separator (one card). Enter 999999 in columns 1-6.

Item 6. Tunnel segment data. Include one card per segment. Data for soft ground and cut-and-cover segments are continued on a second card. Columns 1-4 contain the segment number; the sequence of cards must correspond to the sequence of segments within a reach. The left nodal point number is placed in columns 5-8, right nodal point number in columns 9-12, and the horizontal length of the segment, in feet, in columns 13-20. Columns 21-24 contain the tunnel reach number. The UC strength of intact rock, in pounds per square inch (psi), is entered in columns 25-31 for rock segments only. RQD is entered in columns 32-36 in percent, with any positive number between 25 and 100, for rock or cut-and-cover segments. For cut-and-cover segments, RQD refers to material below

sound rock elevation (see columns 55-60 on continuation card). Excavation method is coded in column 39. Enter code 1 for conventional (drill and blast), 2 for moled rock, 3 for moled soft ground, 4 for soft ground hand excavation, 5 for soft ground ripper excavation, 6 for cut and cover with vertical sidewalls, and 7 for cut and cover with sloping sidewalls. The uniform advance rate is entered in feet per day in columns 40-44. If left blank, COSTUN will calculate the value.

The data base used to form the program's advance rate equations is rather small for moled rock tunnels and moled shafts. Therefore, the user should examine advance rates calculated by COSTUN for these methods to see if they appear reasonable. The uniform advance rate, whether calculated by COSTUN or input by the user, is the advance rate that would be achieved if the segment were sufficiently long to permit work crews and equipment to reach peak efficiency. However, much time is lost during project start-up, when switching to new headings, or when changing excavation methods. Thus, the average advance rate is always less than the computed uniform advance rate. The average advance rate, on which costs are based, is computed internally by COSTUN by making adjustments to the uniform advance rate, as described previously. Water inflow is coded in gallons per minute in columns 45-51 and refers to inflow at the working face. Lining type is entered in column 54 with code 0 for unlined segment, 1 for cast-in-place concrete lining, 2 for shotcrete lining, 3 for precast concrete cut-and-cover box, and 4 for precast concrete segmental lining.

4. The option for precast concrete segmental lining was not included in the original COSTUN program. This subroutine was developed by NED personnel, based on limited experience, and should be used with caution. Adjustments to the cost base for this option are anticipated as experience is gained. This option requires that a lining thickness be input in columns 55-60 and the specified shape be circular with a watertight lining and mole excavation.

5. The user must ensure that the data discussed previously for precast segments are input, or the output will be erroneous. An error message is not printed out for erroneous input on the precast segment

option. Acceptable conditions for other specified lining types, such as the unlined segment (code 0), are: (a) in rock segments if watertight lining is not required (columns 73-75), and (b) in soft ground segments provided the support type on the continuation card (columns 52-54) is code 1, 2, or 3 for cast iron segments, precast concrete segments, or steel segments, respectively. However, an unlined segment is unacceptable in cut-and-cover segments. Lining code 1 or 2 must be used in conjunction with support code 4 in soft ground segments; code 0 or 2 is unacceptable in cut-and-cover segments; and code 3 is unacceptable in rock or soft ground segments. Lining thickness is input in columns 55-60. If left blank, COSTUN will calculate the thickness of cast-in-place concrete lining (code 1 in column 54) or shotcrete (code 2 in column 54). For unlined segments, it will calculate the backplate thickness of soft ground segmental supports (code 1, 2, or 3 in column 54 of continuation card). For precast concrete segmental lining (code 4 in column 54), the thickness must be input. If a thickness is input for code 3 (cut-and-cover precast concrete box), it will be ignored. Rock or soil temperature is coded in degrees Fahrenheit in columns 61-64 for rock and soft ground segments. In column 66, the user should enter code 0 if formwork costs for cast-in-place concrete lining are to be computed and code 1 if formwork costs are to be eliminated. Code 1 should be used when the concrete is cast behind the steel liner plate that serves at the form. Groundwater elevation is input in columns 67-72. The average groundwater elevation within the segment should be used. Column 75 is used to designate whether a watertight lining is required. In this column, the user should enter code 0 for a drained lining or drained soft ground support, or for groundwater elevation below the segment invert elevation, and code 1 for watertight lining or soft ground tunnel support. A cut-and-cover lining is automatically designated watertight. Tunnel type is coded in column 80 with 1 for rock, 2 for soil, and 3 for cut and cover.

Item 7. Tunnel segment continuation card. Include one card for each soft ground or cut-and-cover segment immediately after the main segment card to which it applies. Enter data as follows:

Columns 5-8 - Left-ground surface nodal point number.

Columns 9-12 - Right-ground surface nodal point number.

Columns 13-20 - Effective grain size D_{10}, in millimetres.

Columns 21-24 - Enter the undrained angle of internal friction ϕ in degrees.

Columns 25-31 - Enter undrained soil cohesion, in pounds per square foot (psf).

Columns 32-36 - Enter saturated unit weight of soil, in pounds per cubic foot (pcf). If no value is input, COSTUN uses the default value of 120 pcf.

Columns 37-39 - Enter dewatering option; use code 0 if dewatering is not permitted. Code 1 must be used for sloping-sided open cuts if groundwater elevation is above the bottom of the trench and the impervious layer is below groundwater elevation.

Columns 40-44 - Enter average elevation of groundwater within segment.

Columns 45-51 (optional input) - Enter soil permeability, in centimetres per second (cm/sec), for the strata in which dewatering or face stabilization will occur. If no value is input, COSTUN will compute from the empirical relationship

$$K = CD_{10}^2$$

where C is an empirical factor and D_{10} is the effective grain size in millimetres.

Column 54 (support type) - Enter code 0 for sloping-sided open cuts, 1 for soft ground supported by cast iron segments, 2 for soft ground supported by precast concrete segments, 3 for soft ground supported by steel segments, 4 for soft ground supported by steel ribs and lagging (used with lining codes 1 or 2 in column 54 of main segment card), 5 for vertical-sided open cuts supported by soldier piles and lagging, and 6 for vertical-sided open cuts supported by slurry walls.

Columns 55-60 - Required only for cut and cover. Enter the average sound rock elevation within the segment, below which RQD is greater than or equal to 50.

Column 64 - Required only for cut and cover. Enter the method of bracing open cuts with code 0 for sloping-sided open cuts, 1 for exclusive use of

struts, 2 for exclusive use of tieback anchors, and 3 for struts above the box roof and tieback anchors below the box roof.

Column 66 - Required only for cut and cover. Enter the decking requirement option with codes 0 and 1 to be used for no decking, respectively.

Columns 67-72 (optional input) - Enter stability number. For vertical open cuts, enter the value above sound rock including benefits of dewatering. For soft ground tunnels, enter the value at the face, after stabilization. Leave blank for sloping-sided open cuts or when it is desired to let COSTUN compute the value. For soft ground segments, the stability number input must be between 0 and 9 if the angle of internal friction is less than 29 deg and must be between 0 and 7 if the angle of internal friction is greater than or equal to 29 deg.

Column 74 - Required only for soft ground. Enter the soft ground face stabilization method with code 0 if no stabilization method is to be used, or if 1 or 2 is entered in column 75, 1 for compressed air, 2 for dewatering, and 3 for ground injections.

Column 75 - Required only for soft ground. Enter code 1 to allow COSTUN to select method for face stabilization and check for increased stability (reduce stabilization number) based solely on input parameters and internal calculations. Use code 2 to have COSTUN select a stabilization method only if the tunnel otherwise cannot be excavated, 3 to have COSTUN use the preferred method entered in column 74 above only if the tunnel otherwise could not be excavated, and 4 if the method entered in column 74 is to be used regardless of face stability. If code 1 or 2 is entered in column 75, column 74 must be blank or contain a zero; if code 3 is entered in column 75, a method must be specified in column 74. Columns 67-72 must be blank if code 1, 2, or 3 is entered in column 75. A stability number or stabilization method must be entered in columns 67-72 if code 4 is entered in column 75.

Columns 76-80 - Required only for soft ground. Enter the air pressure, in psi, between 0 and 50 to be used for face stabilization. Zero must be entered if column 74 does not contain code 1 and if column 75 does not contain code 3 or 4. If compressed air is specified (code 1) or selected in column 74, then the air pressure must be greater than zero in columns 76-80.

Item 8. Data separator (one card). Enter 999999 in columns 1-6.

Item 9. Tunnel reach data. Include one card per reach.

Columns 1-4 - Enter the reach number.

Columns 5-8 - Enter the exit shaft number.

Columns 9-14 - Required only for rock or soft ground. Enter the characteristic finished dimension, in feet, with any number from 10 to 40.

Column 17 - Required only for rock or soft ground. Enter the tunnel shape with code 1 for circular, 2 for horseshoe, and 3 for baskethandle.

Column 20 - Required only for rock or soft ground. Enter the muck transport method with code 1 for truck, 2 for conveyor, 3 for train, and 4 for conveyor in compressed air and truck in free air.

Columns 21-25 (optional input) - Enter the number of work hours per day. If no value is input, the default value of 24 hr is used.

Columns 26-29 (optional input) - Enter the number of work days per week. Default value is 6.

Columns 30-32 - Required only for cut and cover. Enter the number of contiguous box units in a single-level cut-and-cover box.

Columns 33-37 - Required only for cut and cover. Enter finished box width, in feet. For a single-level box, width equals clear span times number of units. For a double-level box, width equals two times the single level width. Any positive number between 10 and 40 may be input.

Columns 38-42 - Required only for cut and cover. Enter finished box height, in feet. For single-level box, height equals clear height of one unit; height of double-level box equals two times clear height of one unit. Any positive number between 10 and 20 is permissible for a single-level box and between 10 and 40 for a double-level box.

Columns 43-45 - Required only for cut and cover. Enter the select box option with codes 0 and 1 to be used for single-level and double-level box, respectively.

Item 10. Data separator (one card). Enter 999999 in columns 1-6.

Item 11. Shaft segment data. Include one card per segment. Data for soft ground and cut-and-cover segments are continued on a second card. For rock shaft segments, dummy shafts, or portals, the continuation card must be omitted.

Columns 1-4 - Shaft number.

Columns 5-8 - Segment number. Enter any positive integer from 1 to 999. Within any shaft, the segment numbers must be exclusive, but in different shafts, the numbers may be duplicated. Shaft segment numbers need not be in sequence, but sequential arrangement of cards must be from top to bottom of shafts.

Columns 9-12 - Upper nodal point number. Enter the number of the nodal point at the top of the segment.

Columns 13-16 - Lower nodal point number. Enter the number of the nodal point at the bottom of the segment; if a portal, this number should be identical with the upper nodal point number.

Columns 25-32 - Required only for rock. Enter intact, UC rock strength, in psf or in psi, with any positive number. Leave blank when the shaft is a portal.

Columns 33-36 - Required only for rock. Enter RQD in percent, with any positive number from 25 to 100. Leave columns blank when the shaft is a portal.

Columns 37-39 - Required only for rock or soft ground. Enter the excavation method with code 1 for conventional rock excavation, 2 for moled rock excavation, 3 for moled soft ground excavation, or 4 for hand excavation in soft ground. Leave blank when the shaft is a portal or a dummy.*

Columns 40-45 (optional input) - Enter uniform advance rate with any positive number, in feet per working day; if blank or contains a zero, COSTUN computes the advance rate. Leave blank when the shaft is a portal or a dummy.

Columns 46-48 - Rock only. For water inflow, enter code 1 for waterbearing formations; leave blank when the shaft is a portal or for dry formations. Control of inflow in shafts is assumed to be invariant. If inflow occurs, grouting around the perimeter of the shafts is the assumed control method. Costs are based on grout holes drilled on 5-ft centers around the perimeter of the shaft for the entire thickness of the waterbearing formation.

Columns 49-51 - Lining type. For unlined segment, portal, or dummy, enter code 0 or leave blank; for cast-in-place concrete lining, code 1; for shotcrete

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* Note: A dummy shaft is an imaginary shaft used for internal bookkeeping purposes only to separate segments constructed by different excavation methods. No costs are calculated for a dummy shaft.

lining, code 2; and for precast cut-and-cover lining, code 3. An unlined segment is acceptable in rock segments provided a watertight lining (columns 66-68) is not required; in soft ground segments provided the support type (columns 49-51 on continuation card) is code 1, 2, or 3; and in cut-and-cover segments provided the shaft is a portal or a dummy. When lining code 1 or 2 is used in conjunction with support code 4 in soft ground segments, code 1 or 2 is unacceptable in cut-and-cover segments, and code 3 is unacceptable for rock or soft ground segments.

Columns 52-57 (optional input) - For lining thickness, enter any positive number, in inches; leave blank when shaft is a portal or a dummy. A thickness may be input for code 0, 1, or 2 above; for code 0, the value input refers to the backplate thickness of segmented soft ground shaft supports (code 1, 2, or 3 in columns 49-51 of continuation card).

Columns 58-59 - For formwork to be used in conjunction with cast-in-place concrete linings in soft ground or rock segments, enter code 0 or leave blank if formwork costs are to be computed and code 1 if formwork costs are to be eliminated. Code 1 should be used if the concrete is to be cast behind a steel liner that serves as the form. Note that the cost of the steel liner is not computed by COSTUN.

Columns 60-65 - Groundwater elevation. Leave blank for a portal or a dummy shaft. Enter any number representing the average groundwater elevation for the entire shaft.

Columns 66-68 - Watertight lining or soft ground shaft support. For an unlined shaft segment, for a drained lining or drained soft ground support, for a groundwater table below the segment, or for a portal or dummy shaft, enter code 0 or leave blank; for a watertight lining or soft ground shaft support, enter code 1. Note that a cut-and-cover lining is automatically designed as watertight.

Columns 69-73 - Shaft type. For rock, dummy, or portal, enter code 1; for soft ground, code 2; and for cut and cover, code 3.

Item 12. Shaft segment continuation card. Include this card only if the segment is soft ground or cut and cover (code 2 or 3 in columns 69-73 of main card). This card must be placed immediately behind the main card to which it applies.

Columns 17-24 - Effective grain size D_{10}, in millimetres.

Columns 25-32 - For undrained soil cohesion, in psf, enter zero or blank or any positive number. Usually this value is zero for sands and gravels, but it cannot be zero if columns 37-39 below are also zero or blank.

Columns 33-36 (optional input) - For unit weight of soil, in pcf, enter zero or blank or any positive number up to 200. If no value is input, COSTUN will assume 120.

Columns 37-39 - Undrained angle of internal friction, in degrees.

Columns 40-45 - For elevation of impervious layer, enter any number representing the elevation for the segment. Not required for soft ground segments if dewatering is not permitted or if the ground is not capable of being dewatered ($D_{10} \leq 0.08$ mm or PERM ≤ 0.0006 cm/sec); not required for cut-and-cover segments.

Columns 46-48 - Dewatering permitted. For cut-and-cover segments or if lowering of the groundwater table by pumping is not permitted, enter code 0 or leave blank; if lowering of the groundwater table is permitted, enter code 1.

Columns 49-51 - Support type. For soft ground supported by cast iron segments, enter code 1; for soft ground supported by precast concrete segments, code 2; for soft ground supported by steel segments, code 3; for soft ground supported by steel ribs and lagging (used with lining code 1 or 2 in columns 49-51 on main segment card), code 4; and for cut-and-cover construction, code 5.

Columns 52-59 (optional input) - For soil permeability, in cm/sec, enter the permeability at the level in which dewatering or face stabilization will occur; omit for cut-and-cover segments. If no value is input, COSTUN will compute if needed.

Columns 60-65 (optional input) - Stability number. For soft ground segments, enter the value at the face including the effect of any stabilization methods; for cut-and-cover segments, leave blank. If no value is to be input or if it is desired to let COSTUN compute it, enter code 0 or leave blank. Otherwise, input any number from 0 to 9 if PHI < 29 or any number from 0 to 7 if PHI ≥ 29.

Columns 66-67 - Required only for soft ground. Stabilization method; in conjunction with column 68 below, the soft ground face stabilization method either preferred or desired to be used; for required use of no method or for code 1 or 2 in column 68, enter code 0 or leave blank; for stabilization by compressed air, code 1; for stabilization by dewatering, code 2; and for stabilization by ground injections, code 3.

Column 68 - Required only for soft ground. To allow COSTUN to select a face stabilization method and check for a significant reduction in the stability number based solely on input parameters, enter code 1; to have COSTUN select a stabilization method only if the tunnel could not otherwise be excavated, code 2; to have COSTUN use the preferred stabilization method (columns 66-67 above) only if the shaft could not otherwise be excavated, code 3; to have COSTUN use the given stabilization method regardless of the face stability, code 4. For code 1 or 2, a face stabilization method must not be specified in columns 66 and 67; for code 3, a method must be specified in columns 66 and 67; for codes 1, 2, and 3, a stability number must not be input in columns 60-65; and for code 4, either a stability number or a stabilization method (both are also acceptable) must be input (blank or zero in columns 66 and 67 indicates no stabilization method is to be used).

Columns 69-73 - Required only for soft ground. For the air pressure to be used for face stabilization, in psi, input any positive number from 0 to 50. If a stability number is input and the stabilization method selected is compressed air, a number greater than zero must be input; a value other than 0 must not be specified if columns 66-67 do not contain code 1 and if column 68 does not contain code 3 or 4.

Item 13. Data separator (one card). Enter 999999 in columns 1-6.

Item 14. Shaft data. Include one card per shaft.

Columns 1-4 - Shaft number.

Columns 5-10 - Shaft size. Enter the characteristic finished dimension, in feet, with any number from 10 to 40. Leave blank when the shaft is a portal or a dummy.

Columns 11-13 - Shaft shape. For a dummy or portal, enter code 0 or leave blank; for a circular shape, code 1; and for a square shape, code 2.

Columns 14-21 - Distance to disposal. Enter distance to user-selected disposal site, in miles.

Columns 22-28 - Cost of the disposal site, in dollars per acre.

Columns 29-32 - For aboveground air temperature, in degrees Fahrenheit, any positive or negative number is entered but can be omitted if all reaches associated with the shaft are cut and cover.

Columns 33-38 - Labor cost index. Calculate by dividing the cost of labor for period of consideration by costs of labor in Chicago in 1969. This value was $35.17 in Chicago in 1969 and consisted of hourly wages and fringes for heavy construction, one each; common labor plus skilled iron workers plus hoisting engineers plus tractor operators plus air compressor operator plus truck driver. This mix is representative of labor employed in tunnel construction. Rates are published monthly by Engineering News Record (ENR) for 20 cities and annually for an additional 25 cities. In addition, information on labor rates may be obtained by contacting the U. S. Bureau of Labor Statistics, union offices, or local employment offices.

Columns 39-44 - Equipment cost index. Based on ENR quarterly report of "Equipment List Price Trends, All Types of Equipment." Equipment Cost Index is calculated by dividing the index value for the period of consideration by the index value in 1969, which was 110.4 on a base of 100 for 1967.

Columns 45-50 - Material cost index. Calculate by dividing the ENR Construction Cost Index, material prices for location of the project for the period of project construction, by the Chicago index for 1969. The unit of materials to use consists of 22.5 cwt bulk cement, carload lots (prior to 1972 used 6 bbls), 1 Mfbm of pine or fir 2x4's, and 25 cwt standard structural steel shapes, W8x31, base price, FOB warehouse. The 1969 Chicago cost of these mtls was $402.50.

Columns 51-56 - Regional cost factor. Used to assess construction cost differences in various regions of the United States. Enter 0.9 for Chicago, 1.2 for San Francisco, 2.0 for New York City, 0.8 for all other areas, or any other number the user deems appropriate.

Columns 57-61 (optional input) - For work hours per day, enter any positive number from 0 to 24. If no value is input, 24 will be assumed.

Columns 62-65 (optional input) - For work days per week, enter any positive number from 0 to 7. If no value is input, 6 will be assumed.

Item 15. Data separator (one card). Enter 999999 in columns 1-6.

Item 16. End of system (one card). Enter end of system in columns 1-13.

6. At this point, input decks for additional tunnel-shaft systems may be prepared. The additional decks should start with the title cards and end with the end of system card above. The additional system data decks may be stacked for a single computer run. Final job control cards are placed behind the last end of system card.

Fatal errors

7. Data inputs that would cause material inaccuracies in the problem solution and that can be identified by internal checks in subroutines INPUT, SFTSET, and LENCTH are programmed to halt execution of the computations. Such inputs, are, therefore, called "fatal" errors. The following tabulation is a complete listing of all fatal errors checked in INPUT, SFTSET, and LENCTH. The Format Statement Number is the number of the statement in the program listing that will be printed out as a result of the error. All are checked in INPUT except as noted in paragraph 7.

	Format Statement No.	
Description	Tunnels	Shafts
No separator card after nodal point card	1500	1500
Duplicate nodal point number	1013	1013
Nodal point < 1 or > NPMAX* NPMAX = max. no. of nodal points	1001	1001
Number of segments > NTSMAX* or NSSMAX* NTSMAX = max. no. of tunnel segments allowed NSSMAX = max. no. of shaft segments allowed	1016	1017
No separator card after tunnel segment data or tunnel type coded incorrectly	1501/2000	--

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* See the program listing (paragraph 16) for present dimensions of these variables.

Description	Format Statement No. Tunnels	Shafts
Duplicate reach or shaft number	1022	1023
Segment card out of sequence	1015	1115
Nodal point card omitted	1031	1131
Excavation method coded incorrectly	1030	1029
Excavation method does not match tunnel or shaft type	2005	2210
Thickness specified; no lining	1045	1046
Lining type coded incorrectly	1043	1048
Lining type does not match tunnel or shaft type	2010	2220
Input advance rate less than zero	1065	1075
Watertight lining requirement coded incorrectly	2015	2225
No lining or support specified for watertight tunnel or shaft	2020	2230
RQD < 25 in rock tunnel or shaft	2030	2212
RQD < 0 or > 100	1062	1072
Surface nodal point out of sequence	2040	--
Surface nodal point card omitted	2045	--
Surface nodal point elevation below tunnel	2050	--
Effective grain size not specified	2055	2245
Soil strength not specified	2060	2250
Friction angle > 100 deg	2063	2253
Unit weight of soil > 200 pcf	2064	2254
Dewatering requirement coded incorrectly	2065	2255
Impervious layer above ground surface	2072	--
Impervious layer at ground surface, soil not clay	2073	--
Impervious layer above base of shaft segment	--	2262
Support type coded incorrectly	2075	2265
Support type does not match tunnel or shaft type	2080	2270
Lining type does not match support type	2085	2275
Rock elevation above ground surface	2092	--
Bracing code < 0 or > 3	2095	--
Bracing code for vertical cut ≤ 0	2100	--
Decking coded incorrectly	2105	--

Description	Format Statement No. Tunnels	Shafts
Stability number too high; excavation impossible	2115	2285
Stabilization method coded incorrectly	2120	2290
Stabilization use coded incorrectly	2125	2295
Air pressure not specified for compressed air stabilization with input stability number	2130	2300
Stability number specified; incorrect stabilization use code	2135	2305
Air pressure specified; compressed air stabilization not specified	2137	2307
Stabilization use code does not match method	2140	2310
Unacceptable stabilization method input	2147	2320
No separator card after reach data	1502	--
Reach number < 1 or > NTRMAX	1021	--
Size indicates cut-and-cover; shape code is not zero	2150	--
Shape indicates cut and cover; size in wrong column	2151	--
Duplicate reach or shaft data cards	1026	1027
Muck transport method coded incorrectly	1041	--
Shape coded incorrectly	1042	2325
Shape indicates cut and cover; muck transport method specified	2152	--
No muck transport method specified	2153	--
Work hours per day < 0 or > 24	2155	2335
Work days per week < 4 or > 7	2160	2340
Box dimension(s) not input	2165	--
Number of box units not specified for cut and cover	2175	--
Noncircular shape for mole excavation	1040	2355
Compressed air required; truck muck transport specified	2195	--
Cast iron support specified for noncircular shape	2200	2350
Tunnel is not cut and cover; no shape specified	2201	--
Shape specified is not for cut and cover	2202	--
RQD of sound rock < 25 for cut and cover	2204	--
Sloping cut through pervious ground below GWT; dewatering must be allowed	2205	--

Description	Format Statement No. Tunnels	Format Statement No. Shafts
Segment in nonexistent reach or shaft	1200	1201
Reach or shaft number not referred to	1203	1204
Reach ends at nonexistent shaft	1202	--
Shaft number < 1 or $>$ NSMAX	--	1034
Groundwater elevation within shaft segment	--	2240
Shaft inflow coded incorrectly	--	1047
Shape indicates a dummy shaft, size given	--	2330
Size indicates a dummy shaft, shape code not zero or blank	--	2332
Square shaft in rock	--	2345
Missing separator card after shaft segment data, or shaft type coded incorrectly		1503/2207
No separator card after shaft data	--	1504
No cut-and-cover segments in a cut-and-cover shaft (SFTSET)		1000
No cut-and-cover segment adjacent to dummy shaft (LENGTH)	--	2000

8. Fatal errors may also be detected after some preliminary processing in subroutines CALCS, AIRPRS and STABIL that are identified in the program listing. In this case, the calculated tunnel data and calculated shaft data will be printed out (unless suppressed), and then the program execution will be halted. Fatal errors in this category are listed below.

Description	Format Statement No. Tunnels	Format Statement No. Shafts	Subroutine
Stability number too high after stabilization; excavation impossible	2000	3000	STABIL
Stabilization is required but input method not acceptable	2030	3030	STABIL
Stabilization is required but input method not effective	2035	3035	STABIL

Description	Format Statement No. Tunnels	Shafts	Subroutine
Stabilization is required but input specifies no method must be used	2050	3050	STABIL
Excavation impossible by using air pressure < 50 psi	2000	3000	AIRPRS
Haul slope too steep for a train	1020	--	CALCS
Tunnel too small for a truck	1021	--	CALCS
Slope too steep for muck transport methods	1023	--	CALCS
Truck muck transport in compressed air tunnel	1025	--	CALCS

Nonfatal errors

9. Data inputs that are beyond the range for which the cost relationships are believed to apply with accuracy are nonfatal errors. These errors will not halt execution of the program, but a warning will be printed out to call attention to their existence. Included in the category of nonfatal errors are various reminders and warnings as to the final use of certain input data.

Description	Format Statement No. Tunnels	Shafts	Subroutine
Rock strength < 500 psi	1060	1070	INPUT
Cut-and-cover segments are watertight	2017	2227	INPUT
Groundwater elevation is zero or blank, used zero	2025	2235	INPUT
RQD > 25 for soft ground tunnel	2035	2215	INPUT
Coefficient of permeability > 10 cm/sec	2061	2251	INPUT
Friction angle > 45 deg	2062	2251	INPUT
Impervious layer elevation is zero or blank, used zero	2070	2260	INPUT
Rock elevation is zero or blank, used zero	2090	--	INPUT
Cut-and-cover box deeper than 100 ft	2094	--	INPUT
Stabilization method is not acceptable	2145	2315	INPUT
Size < 10 or > 40 ft	1064	1074	INPUT

Description	Format Statement No. Tunnels	Shafts	Subroutine
Box width exceeds 40 ft	2170	--	INPUT
Box height > 20 ft for single-level box	2180	--	INPUT
Box height > 40 ft for double-level box	2185	--	INPUT
Impervious layer above tunnel, D_{10} > 0.005	2190	--	INPUT
RQD of sound rock is 25-50 for cut and cover	2203	--	INPUT
No excavation method specified; dummy shaft assumed	--	2208	INPUT
Dummy shaft, cost=0	--	2327	INPUT
Shaft depth > 3000 ft	--	1071	LENGTH
Reach length > 20 miles	1061	--	LENGTH
Input thickness less than standard design, input ignored	1010	1011	SIZEST/SIZESS
Input thickness appear to be inadequate for water pressure	2710	2711	SIZEST/SIZESS
Lining thickness was input for cut-and-cover box	3500	--	SIZEST/SIZESS
Groundwater below segment; input inflow ignored	3600	3605	SIZEST/SIZESS
Stabilization method not effective; no method used	2010	3010	STABIL
Input stabilization method not required	2015	3015	STABIL
Input stabilization method not acceptable nor required	2020	3020	STABIL
Stabilization method not effective; method used anyway	2025	3025	STABIL
Hand excavation used rather than input method	2040	3040	STABIL
Conveyor/truck transport used rather than input method	1030	--	CALCS

10. Several of the above messages are caused by elevations that are not associated with nodal points. INPUT makes extensive checks for missing input data. Unfortunately, the computer cannot distinguish between a zero and a blank data field. Therefore, COSTUN cannot be certain that the user meant elevation 0 or just forgot to input a number. These messages can be avoided by specifying an elevation close to zero, like 0.1 or 0.01, if elevation 0 is indeed desired.

Program Execution and Printout

Program execution

11. COSTUN is executed in core. During operation it neither refers to information stored on another tape nor generates another data tape. Therefore, no special operating instructions are necessary.

12. The program stores most data in one of five arrays (A, B, CNP, SHAFT, and TRDATA). These five arrays are stored in one main array called ARRAY. This procedure allows the user to alter the storage requirements of COSTUN. The storage requirements are a function of the allowable number of tunnel and shaft segments, tunnel reaches, and shafts. COSTUN as written provided for NTSMAX (maximum number of tunnel segments) = 300, NSSMAX (maximum number of shaft segments) = 300, NSMAX (maximum number of shafts) = 100, and NTRMAX (maximum number of reaches) = 200. The version presented in the program listing allows NTSMAX = 20, NSSMAX = 10, NSMAX = 10, and NTRMAX = 20.

13. The storage requirements can be changed by changing any or all four of these key variables in the main program. If the change is made after the initial compilation, then only the main program needs to be recompiled. If these variables are made larger, the dimension of ARRAY (first execute card in MAINLINE) must be increased. If these variables are made smaller, the dimension of ARRAY need not be changed, but failure to do so will result in paying for more computer storage than necessary. The minimum dimension of ARRAY is given by

[illegible] = 74 X NTSMAX + 46 X NSSMAX + 23 X NSMAX + 23 X NTRMAX

14. For the values originally provided for these four key variables, the minimum dimension of ARRAY was 42,900. If the dimension of ARRAY is changed to less than the minimum required dimension, a message will be printed and the computer run will terminate. Whenever the dimension of ARRAY is changed, the value of MM (fifth execute card in MAINLINE) must also be changed to that of the new dimension of ARRAY. The present dimension of ARRAY is 2630. This size allows most tunnels to be estimated without problems and saves some storage costs.

Printout

15. The printout consists of the tunnel and shaft title and all other input data, unless the suppress option, described previously in paragraph 3, is used to suppress one or more items of input data. After the selected input is printed out, the program prints out calculated tunnel data, consisting of length, slope, excavated dimensions and quantities, advance rates, lining thickness, pump rates and heads, and construction time. Position of the airlock, if used, stabilization method used, unit weights, permeability, concrete volumes, and backfill volumes are listed where appropriate for each tunnel segment within each reach. The same categories of calculated data are printed out for each shaft under the heading, "Calculated Shaft Data." Next, tunnel costs are listed by reach and segment number under column headings for excavation setup, excavation, muck loading, muck hauling, muck hoisting, muck disposal, supports, lining, lining formwork, grouting, pumping, and air conditioning, and these unit costs are tallied to obtain the segment cost per foot and total segment costs, which are printed. This process is repeated for each segment. Then a summary of reach costs is printed, applying the cost adjustment factors to labor costs, equipment costs, and material costs to obtain total reach costs. Such a printout is also prepared for each reach and for each shaft. A "Tunnel Reach Cost Summary" is printed next, applying the Regional Cost Factor to the total, followed by a similar "Shaft Cost Summary." The final output block reprints the project title and the profit and overhead margins, and then lists the project summary costs for labor, equipment, and materials, and the total costs.

Program Listing

16. A listing of program COSTUN is given below.

```
C     MAINLINE PROGRAM ----------  COSTUN ---------------------------
C     ***************************************************************
      DIMENSION ARRAY (2630)
      COMMON /BASIC/ NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON/F/ IERROR,ISTOP
      COMMON/G/ TUNLC,TUNEC,TUNMC,TUNTC
C     ---------------------------------------------------------------
C     WHENEVER THE DIMENSION OF 'ARRAY' IS CHANGED, THE VALUE OF MM
C     BELOW MUST ALSO BE CHANGED TO THAT OF THE NEW DIMENSION OF 'ARRAY'
      MM=2630
C     ---------------------------------------------------------------
      NSMAX=10
      NSSMAX=10
      NTRMAX=20
      NTSMAX=20
      NPMAX=NSSMAX+2*NTSMAX
C     J1 = STORAGE LOCATION IN 'ARRAY' OF FIRST ITEM IN 'A' ARRAY
C     J2 = STORAGE LOCATION IN 'ARRAY' OF FIRST ITEM IN  B' ARRAY
C     J3 = STORAGE LOCATION IN 'ARRAY' OF FIRST ITEM IN 'CNP' ARRAY
C     J4 = STORAGE LOCATION IN 'ARRAY' OF FIRST ITEM IN 'SHAFT' ARRAY
C     J5 = STORAGE LOCATION IN 'ARRAY' OF FIRST ITEM IN 'TRDATA' ARRAY
C     J6 = STORAGE LOCATION IN 'ARRAY' OF FIRST ITEM IN  CUMSL
      J1 = 1
C     THE NUMERICAL COEFFICIENTS ON THE NEXT 5 LINES REPRESENT THE
C     NUMBER OF ITEMS STORED IN THE  A,  B,  CNP,  SHAFT,  AND  TRDATA
C     ARRAYS, RESPECTIVELY
      J2 = J1 + 68*NTSMAX
      J3 = J2 + 43*NSSMAX
      J4 = J3 +  2*NPMAX
      J5 = J4 + 23*NSMAX
      J6 = J5 + 23*NTRMAX
      LI=5
      LO=6
C     ---------------------------------------------------------------
C     THE MINIMUM REQUIRED SIZE OF 'ARRAY' IS  J6+ NPMAX-1
C     OR 74*NTSMAX+46*NSSMAX+23*NSMAX+23*NTRMAX
      MINARR=74*NTSMAX+46*NSSMAX+23*NSMAX+23*NTRMAX
      IF(MM.LT.MINARR) GO TO 500
C     ---------------------------------------------------------------
   10 IERROR=0
      READ(LI,1,END=600) TITLE,LIST,PM,OM,STABEG
      WRITE(LO,2) TITLE
      WRITE(LO,3) PM,OM
      WRITE(LO,4)
      CALL INPUT    (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      IF(ISTOP.EQ.1) GO TO 10
  140 CALL SFTSET   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      IF(ISTOP.EQ.1) GO TO 10
      CALL LENGTH   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1 ARRAY(J6),NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
C     ---------------------------------------------------------------
C     PRINT OUT INPUT DATA FOR TUNNELS
C     INITIALIZE
```

(Continued)

```
      IPR=0
      NLINES=40
      DO 5 M=1,NTS
      I=M
      ITYPE=1
    5 CALL INOUT  (I,ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NLINES,IPR,NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
C     PRINT OUT INPUT DATA FOR SHAFTS
C     INITIALIZE
      IPS=0
      NLINES=45
      DO 6 M=1,NSS
      I=M
      ITYPE=2
    6 CALL INOUT  (I,ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NLINES,IPS,NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
C     ------------------------------------------------------------------
C     CALCULATE TUNNEL DIMENSIONS
      DO 7 M=1,NTS
      I=M
    7 CALL SIZEST(I, ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
C     CALCULATE SHAFT DIMENSIONS
      DO 8 M=1,NSS
      I=M
    8 CALL SIZESS(I, ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
C     ------------------------------------------------------------------
C     DETERMINE STABILITY NUMBER AND EXCAVATION METHOD FOR SG TUNNELS
      DO 20 M=1,NTS
      I=M
      ITYPE=1
      CALL STABIL(I, ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
   20 CONTINUE
C     DETERMINE STABILITY NUMBER AND EXCAVATION METHOD FOR SG SHAFTS
      DO 25 M=1,NSS
      ITYPE=2
      I=M
      CALL STABIL(I, ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
   25 CONTINUE
C     ------------------------------------------------------------------
      CALL REACHD   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL ADRATE   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL CONSTM   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL PUMPHT   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL PUMPRT   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL VOLUME   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL EXCVOL   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)
      CALL MUCKLD   (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),
```

(Continued)

```
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)                                000955
      CALL AIRLOK    (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),  000960 0000
     1 ARRAY(J6),NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)                     000970 0000
      CALL CALCS     (ARRAY(J1),ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),  000980 0000
     1NTSMAX,NSSMAX,NPMAX,NSMAX,NTRMAX)                                000985
      IF(IERROR.EQ.1) GO TO 10                                         000990 0000
      CALL COSTTU    (ARRAY(J1),ARRAY(J3),ARRAY(J4),ARRAY(J5),ARRAY(J6),  001000 0000
     1NTSMAX,NPMAX,NSMAX,NTRMAX,NSSMAX)                                       001005
      CALL COSTSF    (ARRAY(J2),ARRAY(J3),ARRAY(J4),ARRAY(J5),          001010 0000
     1NSSMAX,NPMAX,NSMAX,NTRMAX,NTSMAX)                                       001015
      CALL NEXSET(LO,LI)                                               001020 0000
      GO TO 10                                                         001030 0000
C     ------------------------------------------------------------------ 001040 0000
C     DIMENSION OF 'ARRAY' ARRAY LESS THAN MINIMUM REQUIRED DIMENSION,  001050 0000
C     EXECUTION TERMINATED                                             001060 0000
  500 WRITE(LO,9) MM,MINARR                                            001070 0000
C     ------------------------------------------------------------------ 001080 0000
    1 FORMAT(10(16A4/),40I1,/,3F10.0)                                  001090 0000
    2 FORMAT(1H1,10(/),15X,90(1H*),/,15X,1H*,88X,1H*,/,                001100 0000
     110(15X,1H*,12X,16A4,12X,1H*,/),                                  001110 0000
     2                 15X,1H*,88X,1H*,/,15X,90(1H*))                  001120 0000
    3 FORMAT(/////,44X,32(1H*),/,                                      001130 0000
     1 44X,1H*,22H PROFIT MARGIN .......F7.2,2H *,/,                   001140 0000
     2 44X,1H*,22H OVERHEAD MARGIN .....F7.2,2H *,/,                   001150 0000
     3    44X,32(1H*))                                                 001160 0000
    4 FORMAT(1H1)                                                      001170 0000
    9 FORMAT(1H1,/////,1X,131(1H*)//27X,78H***** EXECUTION OF 'COSTUN' S 001180 0000
     1TOPPED BECAUSE OF ERROR IN MAINLINE PROGRAM *****//22X,           001190 0000
     213HDIMENSION OF ,I7,68H GIVEN FOR 'ARRAY' IN MAINLINE PROGRAM IS L 001200 0000
     3ESS THAN MINIMUM REQUIRED//22X, 13HDIMENSION OF ,I7,             001210 0000
     429H.      ALL DATA DECKS IGNORED.//1X,131(1H*))                  001220 0000
C     ------------------------------------------------------------------ 001230 0000
  600 CONTINUE                                                         001240 0000
      STOP                                                             001245
      END                                                              001250 0000
      SUBROUTINE INPUT(A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,  001262 0000
     1NTRMAX)                                                          001265
C     ----------------------------------------------------------------- 001270 0000
C     ----------------------------------------------------------------- 001280 0000
C     THE FOLLOWING DEFINES THE CONTENTS OF THE VARIOUS ARRAYS         001290 0000
C     ----------------------------------------------------------------- 001300 0000
C     CNP(I,J) .... NODAL POINT ARRAY (I = NODAL POINT NUMBER)         001310 0000
C                             J = 1  STATIONING OF THE NODAL POINT     001320 0000
C                                    (CALCULATED IN SUB LENGTH)        001330 0000
C                               = 2  ELEVATION OF THE NODAL POINT      001340 0000
C     A(I,J) ...... TUNNEL SEGMENT ARRAY (I = LOCATION OF SEGMENT IN   001350 0000
C                   'A' ARRAY,  J = AS BELOW)                          001360 0000
C                        ITEM J = 1   SEGMENT NUMBER = NTSEG           001370 0000
C                                 2   NODAL POINT TO LEFT OF SEGMENT = NPL 001380 0000
C                                 3   NODAL POINT TO RIGHT OF SEGMENT = NPR 001390 0000
C                                 4   REACH NUMBER = NREACH            001400 0000
C                                 5   ROCK STRENGTH = RS OR JRS        001410 0000
C                                 6   R.Q.D. = RQD OR JRQD             001420 0000
C                                 7   EXCAVATION METHOD = MEX          001430 0000
C                                       (1=DRILL AND BLAST, 2=MOLE(ROCK), 001440 0000
C                                       3=MOLE(SOIL), 4=HAND,5=RIPPER  001450 0000
C                                       6=OPEN CUT(VERTICAL), 7=OPEN CUT 001460 0000
C                                       (SLOPING))                     001470 0000
```

(Continued)

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C                       8   HEADING ADVANCE RATE = AR                001490 0000
C                       9   GROUNDWATER INFLOW AT WORKING FACE       001490 0000
C                                = INFLOW OR GI                      001500 0000
C                      10   LINING TYPE = LINING                     001510 0000
C                            (0 OR BLANK=UNLINED,1=CIP CONCRETE,     001520 0000
C                             2=SHOTCRETE,3=PRECAST CONCRETE BOX)    001530 0000
C                      11   LINING THICKNESS = TL OR LT OR TSEG      001540 0000
C                      12   ROCK TEMPERATURE = RTEMP OR JRTEMP       001550 0000
C                      13   SUPPRESSION OF FORMWORK COSTS=NOFORM     001560 0000
C                           (0 OR BLANK=POSSIBLE COSTS,1=SUPPRESS    001570 0000
C                      14   GROUNDWATER ELEVATION = ELWATR           001580 0000
C                      15   WATERTIGHT LINING REQUIREMENT = LINWT    001590 0000
C                                (0 OR BLANK=NO, 1=WATERTIGHT)       001600 0000
C                      16   TUNNEL SEGMENT TYPE = NTSTYP             001610 0000
C                                (1=ROCK, 2=SOFT GROUND,             001620 0000
C                                3= CUT AND COVER)                   001630 0000
C                      17   SURFACE NODAL POINT TO LEFT OF TUNNEL    001640 0000
C                                SEGMENT = NPLS                      001650 0000
C                      18   SURFACE NODAL POINT TO RIGHT OF          001660 0000
C                                TUNNEL SEGMENT = NPRS               001670 0000
C                      19   EFFECTIVE GRAIN SIZE = D10               001680 0000
C                      20   ANGLE OF INTERNAL FRICTION = PHI         001690 0000
C                      21   SOIL COHESION = COHESN                   001700 0000
C                      22   SOIL UNIT WEIGHT = GAMMA                 001710 0000
C                      23   DEWATERING ALLOWED = IWATER              001720 0000
C                                (0 OR BLANK=NO, 1=ALLOWED)          001730 0000
C                      24   ELEVATION OF IMPERVIOUS LAYER = ELIMP    001740 0000
C                      25   SOIL PERMEABILITY = PERM                 001750 0000
C                      26   SUPPORT TYPE = ISUPPT                    001760 0000
C                                (1=CAST IRON SEGMENTS, 2=CONCRETE   001770 0000
C                                SEGMENTS, 3=STEEL SEGMENTS,         001780 0000
C                                4=STEEL RIBS W/LINING, 5=SOLDIER    001790 0000
C                                PILE-LAGGING, 6=SLURRY WALL)        001800 0000
C                      27   ELEVATION OF SOUND ROCK = ELROCK         001810 0000
C                      28   OPEN CUT BRACING REQUIREMENT = IBRACE    001820 0000
C                                (0 OR BLANK=NONE, 1 =STRUTS         001830 0000
C                                2=ANCHORS, 3=STRUTS+ANCHORS)        001840 0000
C                      29   OPEN CUT DECKING REQUIREMENT = IDECK     001850 0000
C                                (0 OR BLANK=NO, 1=DECKING USED)     001860 0000
C                      30   STABILITY NUMBER = STABNO                001870 0000
C                      31   STABILIZATION METHOD = MSTAB             001880 0000
C                                (0 OR BLANK=NONE, 1=COMPRESSED      001890 0000
C                                AIR, 2=DEWATERING, 3=GROUND INJ.)   001900 0000
C                      32   USE OF STABILIZATION METHOD = MUST       001910 0000
C                                (1=COSTUN SELECT, 2=COSTUN SELECT   001920 0000
C                                ONLY IF COULD NOT BE EXCAVATED,     001930 0000
C                                3=USER SELECT ONLY IF COULD NOT     001940 0000
C                                BE EXCAVATED, 4=USER SELECTS,MUST   001950 0000
C                                USE,EVEN IF MSTAB=0)                001960 0000
C                      33   AIR PRESSURE = AIRPR                     001970 0000
C                      34   ACCEPTABLE INPUT STABIL.METHOD= MSTAC    001980 0000
C                                (1=ACCEPTABLE,2=UNACCEPTABLE)       001990 0000
C                      35   MAX AIR QUANTITY FOR COMPRESSED AIR      002000 0000
C                                SETUP = CAVT                        002010 0000
C                      36   NODAL POINT OF AIR LOCK = NPLOCK         002020 0000
C                      37   MAX HEAT EXCHANGE FOR COOLING PLANT      002030 0000
C                                SETUP = QT                          002040 0000
C                      38   FOR ROCK OR SOFT GROUND -----            002050 0000
```

(Continued)

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C                               QUANTITY OF HEAT EXCHANGE IN SEG = Q
C                               FOR CUT AND COVER -----
C                               LENGTH OF SOLD. PILE W/ DECK. = SPDLT
C                                         -- OR --
C                               DEPTH OF SLURRY WALL = DSLURY
C                           39  CHAR. EXC. DIMENSION = BE
C                           40  CHAR. EXC. DIMENSION AT RQD=40 = BE40
C                           41  CHAR. EXC. DIMENSION AT RQD=60 = BE60
C                           42  CHAR. EXC. DIM. W/OB = BOB
C                           43  FOR ROCK -----
C                               CHAR. EXC. DIM. W/OB , RQD=40 = BOB40
C                               FOR CUT AND COVER -----
C                               TOTAL BOX HEIGHT = TOTBOX
C                           44  CHAR. EXC. DIM. W/OB , RQD=60 = BOB60
C                           45  SEGMENT LENGTH = TSEGL
C                           46  MUCK HAUL DISTANCE = DM
C                           47  MUCK HAUL SLOPE = HSLOPE
C                           48  MUCK LOADING RATE IN SEGMENT = RML
C                           49  ULTIMATE ADVANCE RATE = ARTULT
C                           50  CONSTR. TIME EXC. + LINING = CTTS
C                           51  EXCAVATED VOLUME = V
C                           52  TOTAL DEPTH OF TRENCH = DTRNCH
C                           53  CUT AND COVER SIDE CUT SLOPE = SIDESL
C                           54  VOLUME DISPLACED BY CONC. BOX = VBOX
C                           55  VOLUME OF CONCRETE IN BOX = VL
C                           56  AREA OF BOX FORMS = FORMAR
C                           57  PUMPING HEIGHT = PH
C                           58  LENGTH OF PIPE FOR PUMPING INFLOWS
C                                    UPHILL = PIPL
C                           59  AVG PUMPING FLOW IN TUNNELS = FLOW
C                           60  RESIDUAL GROUNDWATER INFLOW = GIR
C                           61  PUMPING FLOW, ONE DEEP WELL = FLOWL
C                           62  CHAR DEPTH OF SUPPORTS = WEB/ TPLATE
C                           63  FOR ROCK OR SOFT GROUND -----
C                               SOIL LOAD  = PSOIL
C                               FOR CUT AND COVER -----
C                               WT/FT OF WALER = WTWALE
C                           64  FOR ROCK OR SOFT GROUND -----
C                               WATER LOAD  = PWATER
C                               FOR CUT AND COVER -----
C                               WT/FT OF STRUT = WTSTRT
C                           65  FOR ROCK OR SOFT GROUND -----
C                               PSOIL+PWATER = PTOTAL
C                               FOR CUT AND COVER -----
C                               WT/FT OF ANCHORS = WTANCH
C                           66  WT/FT OF UNDECKED SOLD. PILE = WTSP
C                           67  WT/FT OF DECKED SOLD. PILE = WTSPD
C                           68  NUMBER OF WELLS = WELLS
C    TRDATA(I,J) . TUNNEL REACH DATA  (I=REACH NUMBER)
C                  ITEM  J = 1  EXIT SHAFT FOR REACH = NSHAFT
C                            2  TUNNEL SIZE = BF
C                            3  TUNNEL SHAPE = ISHAPE
C                                   (0 OR BLANK=CUT AND COVER,
C                               1=CIRCLE, 2=HORSESHOE, 3=BASKETHANDLE
C                            4  MUCK TRANSPORT METHOD = MTM
C                                   (0 OR BLANK=CUT AND COVER,
C                                   1=TRUCK,2=CONVEYOR,3=RAIL,
C                                   4=TRUCK+CONVEYOR IN COMP. AIR)
```

(Continued)

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C                           5    SEGMENT SEQUENCE NUMBER AT WHICH REAC 002640 0000
C                                EXCAVATION BEGINS = NRSEG1             002650 0000
C                           6    NUMBER OF SEGMENTS IN REACH = NSEGS    002660 0000
C                                  - INDICATES REACH GOES FROM RT TO L  002670 0000
C                                  + INDICATES REACH GOES FROM LF TO R  002680 0000
C                           7    PEAK REACH MUCK REMOVAL RATE (CY/HR)   002690 0000
C                           8    WORK HOURS PER DAY = HOURS             002710 0000
C                                  = RMLMAX OR IPRML                    002700 0000
C                           9    WORK DAYS PER WEEK = DAYS              002720 0000
C                          10    FOR ROCK OR SOFT GROUND -----          002730 0000
C                                NUMBER OF SHIELD SETUPS = SETUSH       002740 0000
C                                FOR CUT AND COVER -----                002750 0000
C                                NUMBER OF UNITS IN BOX WIDTH = NBOX    002760 0000
C                          11    FOR ROCK OR SOFT GROUND -----          002770 0000
C                                NUMBER OF MOLE SETUPS = SETUPM         002780 0000
C                                FOR CUT AND COVER -----                002790 0000
C                                TOTAL FINISHED BOX WIDTH = BFBWDT      002800 0000
C                          12    FOR ROCK OR SOFT GROUND -----          002810 0000
C                                NUMBER OF RIPPER SETUPS = SETUPR       002820 0000
C                                FOR CUT AND COVER -----                002830 0000
C                                TOTAL FINISHED BOX HEIGHT = BFBHT      002840 0000
C                          13    DOUBLE BOX DESIGN = IBOX2              002850 0000
C                                  (0 OR BLANK=NO, 1=DOUBLE BOX)        002860 0000
C                          14    FOR ROCK OR SOFT GROUND -----          002870 0000
C                                TOTAL LENGTH IN COMPRESSED AIR = DTCA  002880 0000
C                                FOR CUT AND COVER -----                002890 0000
C                                DEWATERING TIME = TIMEDW               002900 0000
C                          15    TOTAL LENGTH REQUIRING COOLING = DTC   002910 0000
C                          16    MAX LENGTH OF CUT IN WHICH BACKFILL    002920 0000
C                                  CANNOT BE PLACED = OPEN              002930 0000
C                          17    TOTAL COST OF LABOR IN REACH = RCL     002940 0000
C                          18    TOTAL COST OF EQUIP.IN REACH = RCE     002950 0000
C                          19    TOTAL COST OF MATERIAL IN REACH = RCM  002960 0000
C                          20    TOTAL COST OF REACH = RCT              002970 0000
C                          21    MAX CC EXC VOL TO DISPOSAL = VDS       002980 0000
C                          22    VOLUME OF CC BACKFILL FROM CURRENT     002990 0000
C                                  EXCAVATION = VBACEX                  003000 0000
C                          23    VOLUME OF CC BACKFILL FROM PREVIOUS    003010 0000
C                                  DISPOSAL = VBACDS                    003020 0000
C                                                                       003030 0000
C      B(I,J) ...... SHAFT SEGMENT ARRAY  (I = LOCATION OF SEGMENT IN   003040 0000
C                      'B' ARRAY,  J = AS BELOW)                        003050 0000
C                    ITEM J= 1   SHAFT NUMBER = NSHAFT                  003060 0000
C                           2    SHAFT SEGMENT NUMBER = NSSEG           003070 0000
C                           3    UPPER NODAL POINT OF SEGMENT = NPT     003080 0000
C                           4    LOWER NODAL POINT OF SEGMENT = NPB     003090 0000
C                           5    ROCK STRENGTH = RS OR JRS              003100 0000
C                           6    R.Q.D. = RQD OR JRQD                   003110 0000
C                           7    EXCAVATION METHOD = MEX                003120 0000
C                                  (0 OR BLANK=NONE, 1=DRILL AND        003130 0000
C                                  BLAST, 2=MOLE(ROCK), 3=MOLE(SOIL)    003140 0000
C                                  4=HAND)                              003150 0000
C                           8    HEADING ADVANCE RATE = AR              003160 0000
C                           9    GROUNDWATER INFLOW = GI                003170 0000
C                                  (0=DRY, 1=WET)                       003180 0000
C                          10    LINING TYPE = LINING                   003190 0000
C                                  (0=UNLINED, 1=CIP CONCRETE,          003200 0000
C                                  2=SHOTCRETE, 3=PRECAST CONCRETE      003210 0000
```

(Continued)

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C              CUT AND COVER BOX)                        003220 0000
C     11     LINING THICKNESS = TL OR LT OR TSEG         003230 0000
C     12     SUPPRESSION OF FORMWORK COSTS=NOFORM        003240 0000
C            (0 OR BLANK=POSSIBLE COSTS,1=SUPPRESS       003250 0000
C     13     GROUNDWATER ELEVATION = ELLATR              003260 0000
C     14     WATERTIGHT LINING REQUIREMENT = LINWT       003270 0000
C              (0 OR BLANK=NO, 1=WATERTIGHT)             003280 0000
C     15     SHAFT SEGMENT TYPE = NSSTYP                 003290 0000
C              (1=ROCK, 2=SOFT GROUND,                   003300 0000
C              3=CUT AND COVER)                          003310 0000
C     16     EFFECTIVE GRAIN SIZE = D10                  003320 0000
C     17     SOIL COHESION = COHESN                      003330 0000
C     18     SOIL UNIT WEIGHT = GAMMA                    003340 0000
C     19     ANGLE OF INTERNAL FRICTION = PHI            003350 0000
C     20     ELEVATION OF IMPERVIOUS LAYER = ELIMP       003360 0000
C     21     DEWATERING ALLOWED = IWATER                 003370 0000
C              (0 OR BLANK=NO, 1=ALLOWED)                003380 0000
C     22     SUPPORT TYPE = ISUPPT                       003390 0000
C                                  (1=CAST IRON          003400 0000
C              SEGMENTS, 2=CONCRETE SEGMENTS,            003410 0000
C              3=STEEL SEGMENTS, 4=STEEL RIBS W/         003420 0000
C              LINING, 5=OPEN CUT)                       003430 0000
C     23     SOIL PERMEABILITY = PERM                    003440 0000
C     24     STABILITY NUMBER = STABNO                   003450 0000
C     25     STABILIZATION METHOD = MSTAB                003460 0000
C              (0 OR BLANK=NONE, 1=COMPRESSED            003470 0000
C              AIR, 2=DEWATERING, 3=GROUND INJ.)         003480 0000
C     26     USE OF STABILIZATION METHOD = MUST          003490 0000
C              (1=COSTUN SELECT, 2=COSTUN SELECT         003500 0000
C              ONLY IF COULD NOT BE EXCAVATED,           003510 0000
C              3=USER SELECT ONLY IF COULD NOT           003520 0000
C              BE EXCAVATED, 4=USER SELECTS,MUST         003530 0000
C              USE,EVEN IF MSTAB=0)                      003540 0000
C     27     AIR PRESSURE = AIRPR                        003550 0000
C     28     ACCEPTABLE INPUT STABIL.METHOD= MSTAC       003560 0000
C              (1=ACCEPTABLE,2=UNACCEPTABLE)             003570 0000
C     29     CHAR. EXC. DIMENSION = BE                   003580 0000
C     30     FOR ROCK -----                              003590 0000
C            CHAR. EXC. DIMENSION AT RQD=40 = BE40       003600 0000
C            FOR SOFT GROUND -----                       003610 0000
C            SOIL LOAD  = PSOIL                          003620 0000
C     31     FOR ROCK -----                              003630 0000
C            CHAR. EXC. DIMENSION AT RQD=60 = BE60       003640 0000
C            FOR SOFT GROUND -----                       003650 0000
C            PSOIL+PWATER = PTOTAL                       003660 0000
C     32     CHAR. EXC. DIM. W/OB = BOB                  003670 0000
C     33     CHAR. EXC. DIM. W/OB , RQD=40 = BOB40       003680 0000
C     34     CHAR. EXC. DIM. W/OB , RQD=60 = BOB60       003690 0000
C     35     SEGMENT LENTH = SSEGL                       003700 0000
C     36     HOISTING HEIGHT = HH OR SEGDEP              003710 0000
C     37     MUCK LOADING RATE IN SEGMENT = RML          003720 0000
C     38     EXCAVATED VOLUME = V                        003730 0000
C     39     ULTIMATE ADVANCE RATE = ARSULT              003740 0000
C     40     CONSTR. TIME EXC. + LINING = CTSS           003750 0000
C     41     CHAR. DEPTH OF SUPPORTS = WEB/ TPLATE       003760 0000
C     42     PUMPING FLOW, ONE DEEP WELL = FLOWL         003770 0000
C     43     WATER LOAD  = PWATER                        003780 0000
C                                                        003790 0000
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(Continued)

```
C     SHAFT(I,J) .. SHAFT INFORMATION    (I=SHAFT NUMBER)          003800 0000
C                   ITEM  J = 1  LOCATION IN THE 'B' ARRAY IN WHICH TH 003810 0000
C                                FIRST SHAFT SEGMENT OF SHAFT I IS     003820 0000
C                                STORED = NSSEG1                       003830 0000
C                             2  NODAL POINT AT TOP OF SHAFT = NPTS    003840 0000
C                             3  NODAL POINT AT BOTTOM OF SHAFT = NPBS 003850 0000
C                             4  NUMBER OF SEGMENTS IN THIS SHAFT      003860 0000
C                                    = NSEGS                           003870 0000
C                             5  DISTANCE TO THE DISPOSAL SITE = DDS   003880 0000
C                             6  COST OF DISPOSAL SITE = CDS OR ICDS   003890 0000
C                             7  SHAFT SIZE = BF                       003900 0000
C                             8  DEPTH OF SHAFT                        003910 0000
C                             9  TOTAL VOLUME OF EXCAVATED MATERIAL    003920 0000
C                             9  TOTAL VOLUME OF EXCAVATED MATERIAL    003920 0000
C                                    TO BE TAKEN OUT THRU THIS SHAFT   003930 0000
C                            10  PEAK MUCK REMOVAL RATE SHAFT (CY/HR)  003940 0000
C                                    = RMLMAX OR IPRML                 003950 0000
C                            11  AVERAGE SUMMER ABOVE GROUND AIR       003960 0000
C                                TEMPERATURE AT TOP OF SHAFT = AIRTEM  003970 0000
C                                    OR IARTEM                         003980 0000
C                            12  COST FACTOR FOR LABOR      = CFL      003990 0000
C                            13  COST FACTOR FOR EQUIPMENT  = CFE      004000 0000
C                            14  COST FACTOR FOR MATERIALS  = CFM      004010 0000
C                            15  REGIONAL COST FACTOR       = RCF      004020 0000
C                            16  SHAFT SHAPE = ISHAPS                  004030 0000
C                                    (0 OR BLANK=DUMMY, 1=CIRCULAR,    004040 0000
C                                    2=SQUARE)                         004050 0000
C                            17  WORK HOURS PER DAY = HOURS            004060 0000
C                            18  WORK DAYS PER WEEK = DAYS             004070 0000
C                            19  TOTAL COST OF LABOR IN SHAFT = SCL    004080 0000
C                            20  TOTAL COST OF EQUIP IN SHAFT = SCE    004090 0000
C                            21  TOTAL COST OF MATERIAL IN SHAFT = SCM 004100 0000
C                            22  TOTAL COST OF SHAFT = SCT             004110 0000
C                            23  PORTALS = NPORT                       004120 0000
C                                    (0=TRUE SHAFT,1=PORTAL)           004130 0000
C     LIST(I) ..... ARRAY OF PRINTOUT OPTIONS                          004140 0000
C                   ITEM  I = 1  NODAL POINT ELEVATIONS                004150 0000
C                             2  TUNNEL INPUT DATA                     004160 0000
C                             3  SHAFT INPUT DATA                      004170 0000
C                             4  CALCULATED TUNNEL DATA                004180 0000
C                             5  CALCULATED SHAFT DATA                 004190 0000
C                             6  TUNNEL SEGMENT AND REACH COSTS        004200 0000
C                             7  SHAFT SEGMENT AND SHAFT COSTS         004210 0000
C                             8  TUNNEL REACH COST SUMMARY             004220 0000
C                             9  SHAFT COST SUMMARY                    004230 0000
C                         10-40  UNUSED AT PRESENT                     004240 0000
C                 IF THE VALUE OF LIST(I) IS ZERO OR BLANK, LISTING OF 004250 0000
C                 ITEM WILL OCCUR. IF VALUE IS ONE,LISTING WILL BE     004260 0000
C                 SUPPRESSED. ITEM NUMBER IS SAME AS DATA CARD COLUMN  004270 0000
C                 NUMBER.                                              004280 0000
C                                                                      004290 0000
C                                                                      004300 0000
C                                                                      004310 0000
C     -----------------------------------------------------------------004320 0000
C                                                                      004330 0000
C     ***********   INPUT TUNNEL SYSTEM LOCATIONS AND CHARACTERISTICS * 004340 0000
C                                                                      004350 0000
C     -----------------------------------------------------------------004360 0000
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(Continued)

```
C     ------------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON /F/ IERROR,ISTOP
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ------------------------------------------------------------------
C
C
      ISTOP=0
C     ******************************************************************
C
      IPR=0
C     READ NODAL POINTS AND STORE IN CORE  *****************
C
C     INITIALIZE NODAL POINT ARRAY
      DO 15 I=1,NPMAX
   15 CNP(I,2)=-10.E30
C
C     N=NODAL POINT NUMBER,  Y=NODAL POINT ELEVATION
   20 READ(LI,1000) N,Y
C     CHECK FOR MISSING SEPARATOR CARD
      IF (Y.LT.50000.) GO TO 21
      ISTOP = 1
      WRITE (LO,1500)
      GO TO 425
   21 CONTINUE
C     CHECK FOR END OF NODAL POINT COORDINATES
      IF(N.EQ.9999) GO TO 30
      IF(N.GT.NPMAX.OR.N.LE.0) GO TO 25
C
C     CHECK FOR PREVIOUS DEFINITION OF THIS NODAL POINT
      IF(CNP(N,2).GT.-10.E29) ISTOP=1
      IF(CNP(N,2).GT.-10.E29) WRITE (LO,1013) N
      CNP(N,2)=Y
      GO TO 20
   25 WRITE(LO,1001) N,NPMAX
      ISTOP=1
      GO TO 20
C     END OF NODAL POINT INPUT
   30 CONTINUE
C
C     ******************************************************************
C
C     READ TUNNEL SEGMENT INFORMATION AND STORE  ***********
C
C     INITIALIZE TUNNEL SEGMENT ARRAY
      DO 40 I=1,NTSMAX
   40 A(I,1)=-10.E30
C     INITIALIZE THE REACH ARRAY
      DO 41 I=1,NTRMAX
   41 TRDATA(I,1)=-10.E30
C
C     I=SEGMENT SEQUENCE NUMBER
      I=0
   50 I=I+1
C     ------------------------------------------------------------------
C
```

(Continued)

```
C     CHECK FOR MAX NUMBER OF SEGMENT CARDS
      IF(I.LE.NTSMAX) GO TO 52
C     ----------------------------------------------------------------
C     CHECK FOR END OF TUNNEL SEGMENT DATA. NDUM=DUMMY SEGMENT NUMBER
   51 READ(LI,1020) NDUM
      IF(NDUM.EQ.9999) GO TO 75
      WRITE(LO,1016)  NTSMAX
      ISTOP=1
      GO TO 51
C     ----------------------------------------------------------------
C
   52 CONTINUE
C     READ SEGMENT DATA FROM CARD
      READ(LI,1005) (A(I,J),J=1,3),A(I,45) ,(A(I,J),J=4,16)
      NTSEG=A(I,1)
      NREACH=A(I,4)
      NTSTYP=A(I,16)
C     ----------------------------------------------------------------
C     CHECK FOR  LAST TUNNEL CARD
      IF(NTSEG.EQ.9999) GO TO 75
C     CHECK FOR MISSING SEPARATOR CARD
      IF(NTSTYP.NE.0) GO TO 53
      ISTOP = 1
      WRITE(LO,1501)
   53 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER TUNNEL TYPE CODE
      IF(NTSTYP.GE.1.AND.NTSTYP.LE.3) GO TO 530
      ISTOP=1
      WRITE(LO,2000) NTSEG,NREACH
      GO TO 425
  530 CONTINUE
C     ----------------------------------------------------------------
C     READ SECOND SEGMENT DATA CARD IF NOT ROCK TUNNEL
      IF(NTSTYP.GT.1) READ(LI,1006) (A(I,J),J=17,33)
C     ----------------------------------------------------------------
C     CHECK FOR PREVIOUS USE OF REACH NUMBER
      IF(I.EQ.1) GO TO 535
      IF(NREACH.EQ.IPR) GO TO 54
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 535
      WRITE(LO,1022) NTSEG,NREACH
      ISTOP=1
  535 TRDATA(NREACH,1)=0.
   54 CONTINUE
C     ----------------------------------------------------------------
C     CHECK THAT TUNNEL SEGMENT CARDS HAVE BEEN PROPERLY ARRANGED
      IF(I.EQ.1) GO TO 57
   56 IF(A(I,2).EQ.A(I-1,3)) GO TO 57
      WRITE(LO,1015) NTSEG,NREACH
      ISTOP=1
   57 CONTINUE
C     ----------------------------------------------------------------
C     CHECK THAT ALL TUNNEL NODAL POINTS HAVE BEEN INPUT
      NPL=A(I,2)
      NPR=A(I,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
```

(Continued)

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      ELAVG=(ELNPL+ELNPR)/2.
C     BYPASS CHECK FOR NOTAL INPUT
      GO TO 58
      IF(ELNPL.GT.-10.E29.AND.ELNPR.GT.-10.E29) GO TO 58
      WRITE(LO,1031) NTSEG,NREACH
      ISTOP=1
   58 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER EXCAVATION METHODS IN TUNNEL SEGMENTS
      MEX=A(I,7)
      IF(MEX.GE.1.AND.MEX.LE.7) GO TO 65
      ISTOP=1
      WRITE(LO,1030)NTSEG,NREACH
   65 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER EXCAVATION METHOD FOR TUNNEL TYPE SPECIFIED
      IF(NTSTYP.EQ.1.AND.MEX.GT.2) GO TO 650
      IF(NTSTYP.EQ.2.AND.MEX.LT.3.OR.NTSTYP.EQ.2.AND.MEX.GT.5) GO TO 650
      IF(NTSTYP.EQ.3.AND.MEX.LT.6) GO TO 650
      GO TO 655
  650 ISTOP=1
      WRITE(LO,2005) NTSEG,NREACH
  655 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR CONTRADICTION OF SPECIFYING A THICKNESS FOR NO LINING
      LINING=A(I,10)
      IF(NTSTYP.NE.1.OR.LINING.NE.0) GO TO 67
      TL=A(I,11)
      IF(TL.LE.0.001) GO TO 67
      WRITE(LO,1045) NTSEG,NREACH
      ISTOP=1
   67 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER LINING TYPE CODE
C     BYPASS CHECK FOR PROPER LINING CODE
      GO TO 70
      IF(LINING.GE.0.AND.LINING.LE.3) GO TO 68
      WRITE(LO,1043) NTSEG,NREACH
      ISTOP=1
   68 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER LINING CODE FOR TUNNEL TYPE SPECIFIED
      IF(NTSTYP.LT.3.AND.LINING.NE.3.OR.NTSTYP.EQ.3.AND.LINING.EQ.1.OR.
     1NTSTYP.EQ.3.AND.LINING.EQ.3) GO TO 70
      ISTOP=1
      WRITE(LO,2010) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK FOR ADVANCE RATE NOT SPECIFIED
   70 AR=A(I,8)
      IF(AR.EQ.0.0) GO TO 71
C     ------------------------------------------------------------------
C     CHECK FOR ADVANCE RATE LESS THAN 0 FT/DAY
      IF(AR.GT.0.0) GO TO 71
      ISTOP=1
      WRITE(LO,1065) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK FOR ROCK STRENGTH GREATER THAN 500 PSI
   71 RS=A(I,5)
```

(Continued)

```
      IF(RS.LT.500..AND.NTSTYP.EQ.1) WRITE(LO,1060) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR PROPER WATERTIGHT CODE
      LINWT=A(I,15)
      IF(LINWT.EQ.0.OR.LINWT.EQ.1) GO TO 710
      ISTOP=1
      WRITE(LO,2015) NTSEG,NREACH
  710 CONTINUE
C     ----------------------------------------------------------------
C     ALL CUT AND COVER BOX SEGMENTS ARE DESIGNED AS WATERTIGHT -
C     INPUT IGNORED
      IF(NTSTYP.EQ.3.AND.LINWT.EQ.0) WRITE(LO,2017) NTSEG,NREACH
C     ----------------------------------------------------------------
C     A LINING OR SUPPORT MUST BE SPECIFIED WHEN WATERTIGHTNESS REQUIRED
      ISUPPT=A(I,26)
      IF(LINWT.EQ.0.OR.LINING.GT.0) GO TO 711
      IF(NTSTYP.GT.1.AND.ISUPPT.LE.3) GO TO 711
      ISTOP=1
      WRITE(LO,2020) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK IF GROUNDWATER ELEVATION NOT INPUT AND WATERTIGHT REQUIRED
  711 ELWATR=A(I,14)
      IF(LINWT.EQ.1.AND.ELWATR.EQ.0.) WRITE(LO,2025) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK IF TUNNEL TYPE NOT ROCK AND GROUNDWATER ELEV. NOT SPECIFIED
      IF(NTSTYP.GT.1.AND.ELWATR.EQ.0) WRITE(LO,2025) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR PROPER TUNNEL CODE IF RQD IS LESS THAN 25.
      RQD=A(I,6)
      IF(NTSTYP.GT.1.OR.RQD.GE.25.)GO TO 712
      ISTOP=1
      WRITE(LO,2030) NTSEG,NREACH
  712 CONTINUE
C     ----------------------------------------------------------------
C     IS TUNNEL IN SOFT GROUND AND RQD GREATER THAN 25.
      IF(NTSTYP.EQ.2.AND.RQD.GT.25.) WRITE(LO,2035) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR RQD BETWEEN 0 AND 100.
      IF(RQD.GE.0.0.AND.RQD.LE.100.) GO TO 713
      WRITE(LO,1062) NTSEG,NREACH
      ISTOP=1
C     ----------------------------------------------------------------
C     CHECK REMAINING DATA IF TUNNEL IS NOT IN ROCK
  713 IF(NTSTYP.EQ.1) GO TO 74
C     ----------------------------------------------------------------
C     CHECK THAT TUNNEL SURFACE NODAL POINTS HAVE BEEN PROPERLY ARRANGED
      IF(I.EQ.1) GO TO 7130
C     CHECK FOR PREVIOUS SEGMENT IN ROCK
      NSTYPE=A(I-1,16)
      IF(NSTYPE.EQ.1) GO TO 7130
      NPLS=A(I,17)
      NPRS=A(I-1,18)
      IF(NPLS.EQ.NPRS) GO TO 7130
      ISTOP=1
      WRITE(LO,2040) NTSEG,NREACH
C     ----------------------------------------------------------------
 7130 NPLS=A(I,17)
      NPRS=A(I,18)
```

(Continued)

AD-A107 890 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/13
TUNNEL COST-ESTIMATING METHODS.(U)
OCT 81 R D BENNETT
UNCLASSIFIED WES/TR/GL-81-10 NL

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```
      ELNPLS=CNP(NPLS,3)
      ELNPRS=CNP(NPRS,3)
C     CHECK THAT ALL TUNNEL SURFACE NODAL POINTS HAVE BEEN INPUT
      IF(ELNPLS.GT.-10.E20.AND.ELNPRS.GT.-10.E20) GO TO 714
      ISTOP=1
      WRITE(LO,2045) NTSEG,NREACH
  714 CONTINUE
C     ------------------------------------------------------------------
C     CHECK THAT SURFACE NODAL POINT ELEVATIONS ARE ABOVE TUNNEL ELEV.
      IF(ELNPLS.GE.ELNPL.AND.ELNPRS.GE.ELNPR) GO TO 715
      ISTOP=1
      WRITE(LO,2050) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK IF EFFECTIVE GRAIN SIZE IS INPUT
  715 D10=A(I,19)
      IF(D10.GT.0) GO TO 716
      ISTOP=1
      WRITE(LO,2055) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK THAT PHI AND/OR COHESION ARE SPECIFIED
  716 PHI=A(I,20)
      COHESN=A(I,21)
      IF(PHI.GT.0.OR.COHESN.GT.0) GO TO 7160
      ISTOP=1
      WRITE(LO,2060) NTSEG,NREACH
 7160 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR POSSIBLE ERROR IN PERMEABILITY INPUT
      PERM=A(I,25)
      IF(PERM.GT.10) WRITE(LO,2061) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK IF PHI GREATER THAN 45 - WARNING, OR GREATER THAN 100 -ERROR
      IF(PHI.GT.45.) WRITE(LO,2062) NTSEG,NREACH
      IF(PHI.LT.100.) GO TO 7165
      ISTOP=1
      WRITE(LO,2063) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK IF GAMMA GREATER THAN 200
 7165 GAMMA=A(I,22)
      IF(GAMMA.LE.200.) GO TO 717
      ISTOP=1
      WRITE(LO,2064) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK FOR PROPER DEWATERING CODE
  717 IWATER=A(I,23)
      IF(IWATER.EQ.0.OR.IWATER.EQ.1) GO TO 7170
      ISTOP=1
      WRITE(LO,2065) NTSEG,NREACH
C     ------------------------------------------------------------------
C     CHECK IF IMPERVIOUS LAYER IS A REQUIRED INPUT
 7170 IF(NTSTYP.EQ.3) GO TO 718
      MSTAB=A(I,31)
      MUST=A(I,32)
      IF(MUST.GE.3.AND.MSTAB.NE.2) GO TO 7185
      IF(IWATER.EQ.0.OR.PERM.LT.10.E-10.AND.D10.LE.0.08.OR.PERM.GT.
     110.E-10.AND.PERM.LE.0.0006) GO TO 7185
C     ------------------------------------------------------------------
C     CHECK IF DEWATERING ALLOWED AND IMPERVIOUS LAYER NOT SPECIFIED
```

(Continued)

```
C     OR IMPERVIOUS LAYER NOT SPECIFIED FOR CUT AND COVER
  718 ELIMP=A(I,24)
      IF(ELIMP.EQ.0.0) WRITE(LO,2070) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK IF IMPERVIOUS LAYER ELEVATION IS BELOW SURFACE ELEVATION
      ELSURF=(ELNPLS+ELNPRS)/2.
      IF(ELIMP.LE.ELSURF) GO TO 7180
      ISTOP=1
      WRITE(LO,2072) NTSEG,NREACH
 7180 CONTINUE
C     ----------------------------------------------------------------
C     CHECK IF OPEN CUT IS ENTIRELY IN ROCK
      ELROCK=A(I,27)
      IF(NTSTYP.EQ.3.AND.ELROCK.EQ.ELSURF) GO TO 7185
C     ----------------------------------------------------------------
C     CHECK IF IMPERVIOUS LAYER IS AT THE SURFACE AND GRAIN SIZE INPUT
C     DOES NOT INDICATE A CLAY.
      IF(ELIMP.LT.ELSURF.OR.D10.LE.0.005) GO TO 7185
      ISTOP=1
      WRITE(LO,2073) NTSEG,NREACH
 7185 CONTINUE
C     ----------------------------------------------------------------
      IF(MEX.EQ.7) GO TO 7205
C     CHECK FOR PROPER SUPPORT CODE
      IF(ISUPPT.GE.1.AND.ISUPPT.LE.6) GO TO 719
      ISTOP=1
      WRITE(LO,2075) NTSEG,NREACH
  719 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER SUPPORT CODE FOR TUNNEL TYPE SPECIFIED
      IF(NTSTYP.EQ.2.AND.ISUPPT.LE.4.OR.NTSTYP.EQ.3.AND.ISUPPT.GT.4)
     1GO TO 720
      ISTOP=1
      WRITE(LO,2080) NTSEG,NREACH
  720 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER LINING CODE FOR SUPPORT TYPE SPECIFIED
      IF(ISUPPT.LE.3.AND.LINING.EQ.0) GO TO 7205
      IF(ISUPPT.GT.3.AND.LINING.EQ.0) GO TO 7200
      IF(ISUPPT.EQ.4.AND.LINING.NE.3) GO TO 7205
      IF(ISUPPT.GT.4.AND.LINING.NE.2) GO TO 7205
 7200 ISTOP=1
      WRITE(LO,2085) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK IF SOFT GROUND TUNNEL
 7205 IF(NTSTYP.EQ.2) GO TO 725
C     ----------------------------------------------------------------
C     CHECK FOR ROCK ELEV. IF TUNNEL IN CUT AND COVER
      IF(ELROCK.EQ.0.0) WRITE(LO,2090) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK IF ROCK ELEVATION IS BELOW GROUND SURFACE ELEVATION
      IF(ELROCK.LE.ELSURF) GO TO 7210
      ISTOP=1
      WRITE(LO,2092) NTSEG,NREACH
 7210 CONTINUE
C     ----------------------------------------------------------------
C     CHECK IF BOX DEPTH IS GREATER THAN 100 FEET
      DTUN=ELSURF-ELAVG
```

(Continued)

```
      IF(DTUN.GT.100.) WRITE(LO,2094) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR PROPER BRACING CODE
      IBRACE=A(I,28)
      IF(IBRACE.GE.0.AND.IBRACE.LE.3) GO TO 723
      ISTOP=1
      WRITE(LO,2095) NTSEG,NREACH
  723 CONTINUE
C     ----------------------------------------------------------------
C     CHECK IF CUT AND COVER (VERTICAL) AND BRACING CODE NOT SPECIFIED
      DROCK=ELSURF-ELROCK
      IF(IBRACE.GT.0.OR.MEX.NE.6.OR.DROCK.LT.0.1) GO TO 724
      ISTOP=1
      WRITE(LO,2100) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR PROPER DECKING CODE
  724 IDECK=A(I,29)
      IF(IDECK.EQ.0.OR.IDECK.EQ.1) GO TO 74
      ISTOP=1
      WRITE(LO,2105) NTSEG,NREACH
      GO TO 74
C     ----------------------------------------------------------------
C     CHECK FOR HIGH STABILTY NUMBER - MAY RESULT THAT JOB UNEXCAVATABLE
  725 STABNO=A(I,30)
      IF(STABNO.LE.9.AND.PHI.LT.29.OR.STABNO.LE.7.AND.PHI.GE.29)
     1 GO TO 7250
      ISTOP=1
      WRITE(LO,2115) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR PROPER STABILIZATION METHOD CODE
 7250 MSTAB=A(I,31)
      IF(MSTAB.GE.0.AND.MSTAB.LE.3) GO TO 726
      ISTOP=1
      WRITE(LO,2120) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR PROPER USE CODE FOR STABILIZATION METHOD
  726 MUST=A(I,32)
      IF(MUST.GE.1.AND.MUST.LE.4) GO TO 727
      ISTOP=1
      WRITE(LO,2125) NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK FOR AIR PRESSURE INPUT IF STABILITY NUMBER INPUT AND
C     AIR PRESSURE STABILIZATION INPUT
  727 AIRPR=A(I,33)
      IF(STABNO.GT.0.0.AND.MSTAB.EQ.1.AND.AIRPR.EQ.0.0) GO TO 7270
      GO TO 728
 7270 ISTOP=1
      WRITE(LO,2130) NTSEG,NREACH
  728 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR USE CODE =4 WHEN STABILITY NUMBER IS SPECIFIED
      IF(STABNO.EQ.0.0.OR.MUST.EQ.4) GO TO 729
      ISTOP=1
      WRITE(LO,2135) NTSEG,NREACH
  729 CONTINUE
C     ----------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD NOT COMPRESSED AIR BUT AIRPR GT 0
      IF(MSTAB.EQ.1.OR.AIRPR.EQ.0.) GO TO 7290
      ISTOP=1
```

(Continued)

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      WRITE(LO,2137) NTSEG,NREACH
 7290 CONTINUE
C     ---------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD AGREES WITH USE CODE
      IF(MSTAB.GE.0.AND.MUST.EQ.4.OR.MSTAB.GT.0.AND.MUST.EQ.3.OR.
     1MSTAB.EQ.0.AND.MUST.LT.3) GO TO 730
      ISTOP=1
      WRITE(LO,2140) NTSEG,NREACH
  730 CONTINUE
C     ---------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD IS INPUT
      IF(MSTAB.EQ.0) GO TO 74
C     ---------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD IS ACCEPTABLE
      GO TO (731,732,733), MSTAB
C     ---------------------------------------------------------------
C     AIR PRESSURE -- CHECK IF SOIL IS A GRAVEL
  731 IF(PERM.LT.10.E-10.AND.D10.GT.2.) GO TO 734
      IF(PERM.GT.0.4) GO TO 734
C     CHECK IF SOIL IS CLAY
      IF(D10.LE.0.005) GO TO 737
C     CHECK IF TUNNEL ABOVE GROUND WATER TABLE
      IF(ELWATR.LT.ELAVG) GO TO 737
C     CHECK IF WATER HEAD LESS THAN 115 FEET
      IF(ELWATR-ELAVG.LE.115.) GO TO 737
      GO TO 734
C     ---------------------------------------------------------------
C     DEWATERING -- CHECK IF DEWATERING IS ALLOWED
  732 IF(IWATER.EQ.0) GO TO 734
      IF(D10.LE.0.005) GO TO 734
C     CHECK IF TUNNEL IS ABOVE GROUND WATER TABLE
      IF(ELWATR.LT.ELAVG) GO TO 734
C     CHECK IF SOIL IS FINE SAND OR COARSER OR IS REASONABLY PERMEABLE
      IF(PERM.LT.10.E-10.AND.D10.GT.0.08) GO TO 737
      IF(PERM.GT.0.0006) GO TO 737
      GO TO 734
C     ---------------------------------------------------------------
C     GROUND INJECTIONS -- CHECK IF SOIL IS NOT CLAY
  733 IF(D10.GT.0.005) GO TO 737
C     ---------------------------------------------------------------
C     STABILIZATION METHOD IS NOT ACCEPTABLE
  734 MSTAC=2
C     CHECK IF USE CODE EQUALS 4
      IF(MUST.EQ.4) GO TO 735
      WRITE(LO,2145) NTSEG,NREACH
      GO TO 738
  735 ISTOP=1
      WRITE(LO,2147) NTSEG,NREACH
      GO TO 738
C     ---------------------------------------------------------------
C     STABILIZATION METHOD IS ACCEPTABLE
  737 MSTAC=1
  738 A(I,34)=MSTAC
   74 IPR=NREACH
C     ---------------------------------------------------------------
      GO TO 50
C     END OF TUNNEL SEGMENT DATA
   75 CONTINUE
```

(Continued)

```
C
C     ****************************************************************
      NTS=I-1
C     ****************************************************************
C
C     READ REACH DATA FOR TUNNELS
C
C     INITIALIZE REACH ARRAY
      DO 80 I=1,NTRMAX
   80 TRDATA(I,1)=-10.E30
C
C     ------------------------------------------------------------------
C     READ REACH DATA FROM CARD
   81 READ (LI,1020) NREACH,NSHAFT,BFT,ISHAPE,MTM,HOURS,DAYS,NBOX,
     1BFBWDT,BFBHT,IBOX2,ISEPCK
      IF(NREACH.EQ.9999) GO TO 86
C     CHECK FOR MISSING SEPARATOR CARD
      IF(ISEPCK.EQ.0) GO TO 82
      ISTOP = 1
      WRITE (LO,1502)
      GO TO 425
   82 CONTINUE
      IF(NREACH.LE.NTRMAX.AND.NREACH.GT.0) GO TO 84
      WRITE(LO,1021) NREACH,NTRMAX
      ISTOP=1
      GO TO 81
   84 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR FINISHED DIMENSION BETWEEN 10 AND 40 FEET
      IF(ISHAPE.GT.0.AND.BFT.LT.10..OR.ISHAPE.GT.0.AND.BFT.GT.40.)
     1WRITE(LO,1064) NREACH
C     ------------------------------------------------------------------
C     CHECK IF TUNNEL SIZE INPUT AGREES WITH SHAPE CODE
      IF(BFT.EQ.0.AND.ISHAPE.EQ.0.OR.BFT.GT.0.AND.ISHAPE.GT.0) GO TO 840
      ISTOP=1
      IF(ISHAPE.GT.0) WRITE(LO,2150) NREACH
      IF(ISHAPE.EQ.0) WRITE(LO,2151) NREACH
  840 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PREVIOUS USE OF REACH NUMBER
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 85
      WRITE(LO,1026) NREACH
      ISTOP=1
   85 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER MUCK TRANSPORT METHOD CODE
      IF(MTM.GE.0.AND.MTM.LE.4) GO TO 850
      WRITE(LO,1041) NREACH
      ISTOP=1
  850 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER TUNNEL SHAPE CODE
      IF(ISHAPE.GE.0.AND.ISHAPE.LE.3) GO TO 851
      WRITE(LO,1042) NREACH
      ISTOP=1
  851 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF SHAPE CODE AGREES WITH MUCK TRANSPORT METHOD
```

(Continued)

```
      IF(ISHAPE.GT.0.AND.MTM.GT.0.OR.ISHAPE.EQ.0.AND.MTM.EQ.0) GO TO 852
      ISTOP=1
      IF(ISHAPE.EQ.0) WRITE(LO,2152) NREACH
      IF(ISHAPE.GT.0) WRITE(LO,2153) NREACH
  852 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF WORK HOURS PER DAY IN PROPER RANGE
      IF(HOURS.GE.0..AND.HOURS.LE.24.) GO TO 853
      ISTOP=1
      WRITE(LO,2155) NREACH
  853 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF WORK DAYS PER WEEK IN PROPER RANGE
      IF(DAYS.GE.4..AND.DAYS.LE.7..OR.DAYS.EQ.0.) GO TO 854
      ISTOP=1
      WRITE(LO,2160) NREACH
  854 CONTINUE
C     IS THIS AN UNDERGROUND HEADING RATHER THAN CUT AND COVER
      IF(ISHAPE.GT.0) GO TO 858
C     ------------------------------------------------------------------
C     CHECK FOR INPUT VALUES FOR BOX WIDTH AND HEIGHT
      IF(BFBWDT.GT.0.0.AND.BFBHT.GT.0.0) GO TO 855
      ISTOP=1
      WRITE(LO,2165) NREACH
  855 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF TOTAL CLEAR BOX WIDTH EXCEEDS 40 FEET
      IF(BFBWDT.GT.40.) WRITE(LO,2170) NREACH
C     ------------------------------------------------------------------
C     CHECK TYPE OF BOX SECTION
      IF(IBOX2.EQ.1) GO TO 857
C     ------------------------------------------------------------------
C     SINGLE LEVEL BOX -- CHECK IF NUMBER OF BOX UNITS IS SPECIFIED
      IF(NBOX.GT.0) GO TO 856
      ISTOP=1
      WRITE(LO,2175) NREACH
  856 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF BOX HEIGHT IS GREATER THAN 20 FEET
      IF(BFBHT.GT.20.) WRITE(LO,2180) NREACH
      GO TO 858
C     ------------------------------------------------------------------
C     DOUBLE LEVEL BOX -- TWO UNITS HIGH AND TWO UNITS WIDE
C     CHECK IF TOTAL CLEAR BOX HEIGHT EXCEEDS 40 FEET
  857 IF(BFBHT.GT.40.) WRITE(LO,2185) NREACH
  858 CONTINUE
C     ------------------------------------------------------------------
      TRDATA(NREACH,1)=NSHAFT
      TRDATA(NREACH,2)=BFT
      TRDATA(NREACH,3)=ISHAPE
      TRDATA(NREACH,4)=MTM
      TRDATA(NREACH,8)=HOURS
      TRDATA(NREACH,9)=DAYS
      TRDATA(NREACH,10)=NBOX
      TRDATA(NREACH,11)=BFBWDT
      TRDATA(NREACH,12)=BFBHT
      TRDATA(NREACH,13)=IBOX2
      GO TO 81
```

(Continued)

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C     ------------------------------------------------------------------
C     END OF REACH INPUT
   86 CONTINUE
C     ------------------------------------------------------------------
C     CHECK REACH AND SEGMENT INFORMATION FOR COMPATABILITY
C     ------------------------------------------------------------------
      DO 87 I=1,NTS
      NREACH=A(I,4)
      NTSEG=A(I,1)
      NTSTYP=A(I,16)
      MEX=A(I,7)
      BFT=TRDATA(NREACH,2)
      ISHAPE=TRDATA(NREACH,3)
      MTM=TRDATA(NREACH,4)
      ISUPPT=A(I,26)
      MSTAB=A(I,31)
      MUST=A(I,32)
      NPL=A(I,2)
      NPR=A(I,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
      ELAVG=(ELNPL+ELNPR)/2.
      ELWATR=A(I,14)
      ELIMP=A(I,24)
C     IF THE TUNNEL SEGMENT IS MOLED, ITS SHAPE MUST BE CIRCULAR
      IF(MEX.NE.2.AND.MEX.NE.3) GO TO 860
      IF(ISHAPE.EQ.1) GO TO 860
      WRITE(LO,1040) NTSEG,NREACH
      ISTOP=1
  860 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR CUT AND COVER OR ROCK TUNNEL
      IF(NTSTYP.NE.2) GO TO 865
C     ------------------------------------------------------------------
C     CHECK IF IMPERVIOUS LAYER IS A REQUIRED INPUT
      IF(MUST.GE.3.AND.MSTAB.NE.2) GO TO 861
      IWATER=A(I,23)
      D10=A(I,19)
      PERM=A(I,25)
      IF(IWATER.EQ.0.OR.PERM.LT.10.E-10.AND.D10.LE.0.08.OR.PERM.GT.
     110.E-10.AND.PERM.LE.0.0006) GO TO 861
C     CHECK IF IMPERVIOUS LAYER IS ABOVE TUNNEL WHEN DEWATERING MAY
C     BE USED AS A STABILIZATION METHOD
      IF(ELIMP.LT.ELAVG+BFT/2.) GO TO 861
      WRITE(LO,2190) NTSEG,NREACH
      A(I,24)=ELAVG-BFT/2.
  861 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF TRUCK TRANSPORT IS SPECIFIED AND COMPRESSED AIR REQUIRED
      IF(MTM.NE.1.OR.MSTAB.GT.1.OR.MSTAB.EQ.0.OR.MUST.LT.4) GO TO 863
      ISTOP=1
      WRITE(LO,2195) NTSEG,NREACH
  863 CONTINUE
C     ------------------------------------------------------------------
C     CAST IRON TUNNEL SUPPORT - CIRCULAR TUNNELS ONLY
      IF(ISUPPT.GT.1.OR.ISHAPE.EQ.1) GO TO 865
      ISTOP=1
      WRITE(LO,2200) NTSEG,NREACH
```

(Continued)

```
  865 CONTINUE
C     -----------------------------------------------------------------
C     CHECK IF SHAPE CODE AGREES WITH TUNNEL TYPE
      IF(NTSTYP.LT.3.AND.ISHAPE.GT.0) GO TO 867
      IF(NTSTYP.EQ.3.AND.ISHAPE.EQ.0) GO TO 867
      ISTOP=1
      IF(NTSTYP.LT.3) WRITE(LO,2201) NTSEG,NREACH
      IF(NTSTYP.EQ.3) WRITE(LO,2202) NTSEG,NREACH
C     -----------------------------------------------------------------
C     CHECK FOR CUT AND COVER EXCAVATION
  867 IF(NTSTYP.NE.3) GO TO 87
      BFBHT=TRDATA(NREACH,13)
C     -----------------------------------------------------------------
C     CHECK IF SOUND ROCK LINE IS ABOVE BASE OF TRENCH AND RQD IS LESS
C     THAN 50
      RQD=A(I,6)
      ELROCK=A(I,27)
      IF(RQD.GE.50..OR.ELROCK.LT.ELAVG-BFBHT/2.) GO TO 869
      IF(RQD.GE.25.) WRITE(LO,2203) NTSEG,NREACH
      IF(RQD.GE.25.) GO TO 869
      ISTOP=1
      WRITE(LO,2204) NTSEG,NREACH
  869 CONTINUE
C     -----------------------------------------------------------------
C     CHECK FOR WATER TABLE ABOVE BASE OF TRENCH AND ABOVE IMPERVIOUS
C     LAYER FOR SLOPING CUT EXCAVATION -- IWATER MUST EQUAL 1
      IF(MEX.NE.7) GO TO 87
      IWATER=A(I,23)
      IF(IWATER.EQ.1) GO TO 87
      IF(ELWATR.LT.ELAVG-BFBHT/2..OR.ELWATR.LE.ELIMP)  GO TO 87
      ISTOP=1
      WRITE(LO,2205) NTSEG,NREACH
C     -----------------------------------------------------------------
   87 CONTINUE
C
C     *****************************************************************
C
C     READ SHAFT SEGMENT DATA   ****************************
C
C     INITIALIZE SHAFT SEGMENT ARRAY
      DO 88 I=1,NSSMAX
   88 B(I,1)=-10.E30
C     INITIALIZE THE SHAFT ARRAY
      DO 89 I=1,NSMAX
   89 SHAFT(I,1)=-10.E30
      IPS=0
      I=0
   90 I=I+1
C
C     -----------------------------------------------------------------
C     CHECK FOR MAX NUMBER OF SHAFT SEGMENTS
      IF(I.LE.NSSMAX) GO TO 95
C     -----------------------------------------------------------------
C     CHECK FOR END OF SHAFT SEGMENT DATA. NDUM=DUMMY SEGMENT NUMBER
   91 READ(LI,1020) NDUM
      IF(NDUM.EQ.9999) GO TO 130
      WRITE(LO,1017) NSSMAX
      ISTOP=1
```

(Continued)

```
      GO TO 91
C
C     ----------------------------------------------------------------
C     READ SHAFT SEGMENT DATA FROM CARD
   95 READ(LI,1007)         (B(I,J),J=1,15)
      NSHAFT=B(I,1)
      NSSEG=B(I,2)
      NSSTYP=B(I,15)
C     ----------------------------------------------------------------
C     CHECK FOR LAST SHAFT CARD
      IF(NSHAFT.EQ.9999) GO TO 130
      IF(NSHAFT.LE.NSMAX.AND.NSHAFT.GT.0) GO TO 100
      WRITE(LO,1034) NSHAFT,NSSEG,NSMAX
      ISTOP=1
  100 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR MISSING SEPARATOR CARD
      IF(NSSTYP.NE.0) GO TO 101
      ISTOP=1
      WRITE(LO,1503)
  101 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER SHAFT TYPE CODE
      IF(NSSTYP.GE.1.AND.NSSTYP.LE.3) GO TO 102
      ISTOP=1
      WRITE(LO,2207) NSSEG,NSHAFT
      GO TO 425
  102 CONTINUE
C     ----------------------------------------------------------------
C     READ SECOND SEGMENT DATA CARD IF NOT ROCK TUNNEL
      IF(NSSTYP.GT.1) READ(LI,1008) (B(I,J),J=16,27)
C     ----------------------------------------------------------------
C     CHECK FOR PREVIOUS USE OF SHAFT NUMBER
      IF(I.EQ.1) GO TO 105
      IF(NSHAFT.EQ.IPS) GO TO 106
      IF(SHAFT(NSHAFT,1).LT.-10.E29) GO TO 105
      WRITE(LO,1023) NSSEG,NSHAFT
      ISTOP=1
  105 SHAFT(NSHAFT,1)=0.
  106 CONTINUE
C     ----------------------------------------------------------------
C     CHECK THAT SHAFT SEGMENT CARDS HAVE BEEN PROPERLY ARRANGED
      IF(I.EQ.1) GO TO 108
      IF(IPS.NE.NSHAFT) GO TO 108
      IF(B(I,3).EQ.B(I-1,4)) GO TO 108
      WRITE(LO,1115) NSSEG,NSHAFT
      ISTOP=1
  108 CONTINUE
C     ----------------------------------------------------------------
C     CHECK THAT ALL SHAFT NODAL POINTS HAVE BEEN INPUT
      NPT=B(I,3)
      NPB=B(I,4)
      ELNPT=CNP(NPT,2)
      ELNPB=CNP(NPB,2)
      IF(ELNPT.GT.-10.E29.AND.ELNPB.GT.-10.E29) GO TO 110
      WRITE(LO,1131) NSSEG,NSHAFT
      ISTOP=1
  110 CONTINUE
```

(Continued)

```
C     ------------------------------------------------------------------
C     CHECK FOR SHAFT BEING A PORTAL. IF SO,RECCRD THIS FACT
      NPORT=0
      IF(NPT.EQ.NPB) NPORT=1
      SHAFT(NSHAFT,23)=NPORT
C     IF SHAFT IS A PORTAL ,SKIP THE FOLLOWING INPUT CHECKS
      IF(NPT.EQ.NPB) GO TO 128
C     -------------------------------------------------------------------
C     CHECK FOR PROPER EXCAVATION METHOD
      MEX=B(I,7)
      IF(MEX.GE.0.AND.MEX.LE.4) GO TO 112
      ISTOP=1
      WRITE(LO,1029) NSSEG,NSHAFT
  112 CONTINUE
C     -------------------------------------------------------------------
C     CHECK FOR DUMMY SHAFT AND BYPASS FURTHER CHECKS
      LINING=B(I,10)
      RS=B(I,5)
      RQD=B(I,6)
      IF(NSSTYP.EQ.1.AND.RS.LE.0..AND.RQD.LE.0.
     1 .AND.MEX.EQ.0.AND.LINING.EQ.0) GO TO 129
  113 CONTINUE
C     -------------------------------------------------------------------
C     CHECK FOR PROPER EXCAVATION METHOD FOR SHAFT TYPE SPECIFIED
      IF(NSSTYP.EQ.1.AND.MEX.LT.1.OR.NSSTYP.EQ.1.AND.MEX.GT.2) GO TO 114
      IF(NSSTYP.EQ.2.AND.MEX.LT.3) GO TO 114
      IF(NSSTYP.EQ.3.AND.MEX.GT.0) GO TO 114
      GO TO 115
  114 ISTOP=1
      WRITE(LO,2210) NSSEG,NSHAFT
C     -------------------------------------------------------------------
C     CHECK FOR ADVANCE RATE NOT SPECIFIED
  115 AR=B(I,8)
      IF(AR.EQ.0.0) GO TO 120
C     -------------------------------------------------------------------
C     CHECK FOR ADVANCE RATE LESS THAN 0 FT/DAY
      IF(AR.GT.0.0) GO TO 120
      ISTOP=1
      WRITE(LO,1075) NSSEG,NSHAFT
C     -------------------------------------------------------------------
C     CHECK FOR ROCK STRENGTH GREATER THAN 500 PSI
  120 CONTINUE
      IF(RS.LT.500..AND.NSSTYP.EQ.1) WRITE(LO,1070) NSSEG,NSHAFT
C     -------------------------------------------------------------------
C     CHECK FOR PROPER SHAFT CODE IF RQD IS LESS THAN 25.
      IF(NSSTYP.GT.1.OR.RQD.GE.25.) GO TO 122
      ISTOP=1
      WRITE(LO,2212) NSSEG,NSHAFT
  122 CONTINUE
C     -------------------------------------------------------------------
C     IS SHAFT IN SOFT GROUND AND RQD GREATER THAN 25.
      IF(NSSTYP.EQ.2.AND.RQD.GT.25.) WRITE(LO,2215) NSSEG,NSHAFT
C     -------------------------------------------------------------------
C     CHECK FOR RQD BETWEEN 0 AND 100.
      IF(RQD.GE.0.0.AND.RQD.LE.100.) GO TO 126
      WRITE(LO,1072) NSSEG,NSHAFT
      ISTOP=1
  126 CONTINUE
```

(Continued)

```
C     ------------------------------------------------------------------
C     CHECK FOR CONTRADICTION OF SPECIFYING A THICKNESS FOR NO LINING
      LINING=B(I,10)
      IF(LINING.NE.0.OR.NSSTYP.NE.1) GO TO 127
      TL=B(I,11)
      IF(TL.LE.0.001) GO TO 127
      WRITE(LO,1046) NSSEG,NSHAFT
      ISTOP=1
  127 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER LINING TYPE CODE
      IF(LINING.GE.0.AND.LINING.LE.3) GO TO 1270
      WRITE(LO,1048) NSSEG,NSHAFT
      ISTOP=1
 1270 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PROPER LINING CODE FOR SHAFT TYPE SPECIFIED
      IF(NSSTYP.LT.3.AND.LINING.NE.3.OR.NSSTYP.EQ.3.AND.LINING.EQ.3)
     1GO TO 1272
      ISTOP=1
      WRITE(LO,2220) NSSEG,NSHAFT
C     ------------------------------------------------------------------
C     CHECK FOR PROPER WATERTIGHT CODE
 1272 LINWT=B(I,14)
      IF(LINWT.EQ.0.OR.LINWT.EQ.1) GO TO 1274
      ISTOP=1
      WRITE(LO,2225) NSSEG,NSHAFT
 1274 CONTINUE
C     ------------------------------------------------------------------
C     ALL CUT AND COVER BOX SEGMENTS ARE DESIGNED AS WATERTIGHT -
C     INPUT IGNORED
      IF(NSSTYP.EQ.3.AND.LINWT.EQ.0) WRITE(LO,2227) NSSEG,NSHAFT
C     ------------------------------------------------------------------
C     A LINING OR SUPPORT MUST BE SPECIFIED WHEN WATERTIGHTNESS REQUIRED
      ISUPPT=B(I,22)
      IF(LINWT.EQ.0.OR.LINING.GT.0) GO TO 1276
      IF(NSSTYP.GT.1.AND.ISUPPT.LE.3) GO TO 1276
      ISTOP=1
      WRITE(LO,2230) NSSEG,NSHAFT
C     ------------------------------------------------------------------
C     CHECK IF GROUNDWATER ELEVATION NOT INPUT AND WATERTIGHT REQUIRED
 1276 ELWATR=B(I,13)
      IF(LINWT.EQ.1.AND.ELWATR.EQ.0) WRITE(LO,2235) NSSEG,NSHAFT
C     ------------------------------------------------------------------
C     CHECK IF SHAFT NOT IN ROCK AND GROUNDWATER ELEV NOT SPECIFIED
      IF(NSSTYP.GT.1.AND.ELWATR.EQ.0) WRITE(LO,2235) NSSEG,NSHAFT
C     ------------------------------------------------------------------
C     CHECK IF GROUND WATER ELEVATION IS IN MIDDLE OF SHAFT SEGMENT
      IF(ELWATR.GE.ELNPT.OR.ELWATR.LE.ELNPB) GO TO 1277
      ISTOP=1
      WRITE(LO,2240) NSSEG,NSHAFT
C     ------------------------------------------------------------------
C     CHECK REMAINING DATA IF SHAFT IS NOT IN ROCK
 1277 IF(NSSTYP.EQ.1) GO TO 128
C     ------------------------------------------------------------------
C     CHECK IF EFFECTIVE GRAIN SIZE IS INPUT
      D10=B(I,16)
      IF(D10.GT.0) GO TO 1278
```

(Continued)

```
      ISTOP=1
      WRITE(LO,2245) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK THAT PHI AND/OR COHESION ARE SPECIFIED
 1278 PHI=B(I,19)
      COHESN=B(I,17)
      IF(PHI.GT.0..OR.COHESN.GT.0.) GO TO 1279
      ISTOP=1
      WRITE(LO,2250) NSSEG,NSHAFT
 1279 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR POSSIBLE ERROR IN PERMEABILITY INPUT
      PERM=B(I,23)
      IF(PERM.GT.10.) WRITE(LO,2251) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK IF PHI GREATER THAN 45 - WARNING, OR GREATER THAN 100 -ERROR
      IF(PHI.GT.45.) WRITE(LO,2252) NSSEG,NSHAFT
      IF(PHI.LT.100.) GO TO 1280
      ISTOP=1
      WRITE(LO,2253) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK IF GAMMA GREATER THAN 200.
 1280 GAMMA=B(I,18)
      IF(GAMMA.LE.200.) GO TO 1281
      ISTOP=1
      WRITE(LO,2254) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK FOR PROPER DEWATERING CODE
 1281 IWATER=B(I,21)
      IF(IWATER.EQ.0.OR.IWATER.EQ.1) GO TO 1282
      ISTOP=1
      WRITE(LO,2255) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK IF IMPERVIOUS LAYER IS A REQUIRED INPUT
 1282 MSTAB=B(I,25)
      MUST=B(I,26)
      IF(MUST.GE.3.AND.MSTAB.NE.2) GO TO 1284
      IF(IWATER.EQ.0.OR.PERM.LT.10.E-10.AND.D10.LE.0.08.OR.PERM.GT.
     110.E-10.AND.PERM.LE.0.0006) GO TO 1284
C     ----------------------------------------------------------------
C     DEWATERING IS ALLOWED.  CHECK IF IMPERVIOUS LAYER IS NOT
C     SPECIFIED OR IF THE IMPERVIOUS LAYER IS ABOVE BASE OF SEGMENT.
      ELIMP=B(I,20)
      IF(ELIMP.EQ.0.0) WRITE(LO,2260) NSSEG,NSHAFT
      IF(ELIMP.LE.ELNPB) GO TO 1284
      ISTOP=1
      WRITE(LO,2262) NSSEG,NSHAFT
 1284 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER SUPPORT CODE
      IF(ISUPPT.GE.1.AND.ISUPPT.LE.5) GO TO 1285
      ISTOP=1
      WRITE(LO,2265) NSSEG,NSHAFT
 1285 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER SUPPORT CODE FOR SHAFT TYPE SPECIFIED
      IF(NSSTYP.EQ.2.AND.ISUPPT.GT.0.OR.NSSTYP.EQ.3.AND.ISUPPT.EQ.5)
     1GO TO 1286
```

(Continued)

```
      ISTOP=1
      WRITE(LO,2270) NSSEG,NSHAFT
 1286 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR PROPER LINING CODE FOR SUPPORT TYPE SPECIFIED
      IF(ISUPPT.LE.3.AND.LINING.EQ.0) GO TO 1288
      IF(ISUPPT.EQ.5.AND.LINING.EQ.3) GO TO 1288
      IF(ISUPPT.EQ.4.AND.LINING.EQ.0) GO TO 1287
      IF(ISUPPT.EQ.4.AND.LINING.NE.3) GO TO 1288
 1287 ISTOP=1
      WRITE(LO,2275) NSSEG,NSHAFT
 1288 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR CUT AND COVER SHAFT
      IF(NSSTYP.EQ.3) GO TO 129
C     ----------------------------------------------------------------
C     CHECK FOR HIGH STABILITY NUMBER - MAY RESULT IN UNEXCAVATABLE JOB
      STABNO=B(I,24)
      IF(STABNO.LE.9.AND.PHI.LT.29.OR.STABNO.LE.7.AND.PHI.GE.29)
     1 GO TO 1289
      ISTOP=1
      WRITE(LO,2285) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK FOR PROPER STABILIZATION CODE
 1289 MSTAB=B(I,25)
      IF(MSTAB.GE.0.AND.MSTAB.LE.3)  GO TO 1290
      ISTOP=1
      WRITE(LO,2290) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK FOR PROPER USE OF STABILIZATION METHOD CODE
 1290 MUST=B(I,26)
      IF(MUST.GE.1.AND.MUST.LE.4) GO TO 1292
      ISTOP=1
      WRITE(LO,2295) NSSEG,NSHAFT
C     ----------------------------------------------------------------
C     CHECK FOR AIR PRESSURE INPUT IF STABILITY NUMBER INPUT AND
C     AIR PRESSURE STABILIZATION INPUT
 1292 AIRPR=B(I,27)
      IF(STABNO.GT.0.0.AND.MSTAB.EQ.1.AND.AIRPR.EQ.0.0) GO TO 1293
      GO TO 1294
 1293 ISTOP=1
      WRITE(LO,2300) NSSEG,NSHAFT
 1294 CONTINUE
C     ----------------------------------------------------------------
C     CHECK FOR USE CODE=4 WHEN STABILITY NUMBER IS SPECIFIED
      IF(STABNO.EQ.0.OR.MUST.EQ.4) GO TO 1296
      ISTOP=1
      WRITE(LO,2305) NSSEG,NSHAFT
 1296 CONTINUE
C     ----------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD NOT COMPRESSED AIR BUT AIRPR GT 0
      IF(MSTAB.EQ.1.OR.AIRPR.EQ.0.) GO TO 1297
      ISTOP=1
      WRITE(LO,2307) NSSEG,NSHAFT
 1297 CONTINUE
C     ----------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD AGREES WITH USE CODE
      IF(MSTAB.GE.0.AND.MUST.GT.2.OR.MSTAB.EQ.0.AND.MUST.LT.3)GO TO 1298
```

(Continued)

```
      ISTOP=1
      WRITE(LO,2310) NSSEG,NSHAFT
 1298 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD IS INPUT
      IF(MSTAB.EQ.0) GO TO 128
C     ------------------------------------------------------------------
C     CHECK IF STABILIZATION METHOD IS ACCEPTABLE
      GO TO (1300,1302,1304), MSTAB
C     ------------------------------------------------------------------
C     AIR PRESSURE -- CHECK IF SOIL IS A GRAVEL
 1300 IF(PERM.LT.10.E-10.AND.D10.GT.2.) GO TO 1305
      IF(PERM.GT.0.4) GO TO 1305
C     CHECK IF SOIL IS A CLAY
      IF(D10.LE.0.005) GO TO 1308
C     CHECK IF SHAFT SEGMENT ABOVE WATER TABLE
      IF(ELWATR.LE.ELNPB) GO TO 1308
C     CHECK IF WATER HEAD LESS THAN 115 FEET
      ELAVG=(ELNPT+ELNPB)/2.
      IF(ELWATR-ELAVG.LE.115.) GO TO 1308
      GO TO 1305
C     ------------------------------------------------------------------
C     DEWATERING -- CHECK IF DEWATERING IS ALLOWED
 1302 IF(IWATER.EQ.0) GO TO 1305
C     CHECK IF SHAFT SEGMENT ABOVE WATER TABLE
      IF(ELWATR.LE.ELNPB) GO TO 1305
C     CHECK IF SOIL IS FINE SAND OR COARSER OR IS REASONABLY PERMEABLE
      IF(PERM.LT.10.E-10.AND.D10.GT.0.08) GO TO 1308
      IF(PERM.GT.0.0006) GO TO 1308
      GO TO 1305
C     ------------------------------------------------------------------
C     GROUND INJECTIONS -- CHECK IF SOIL IS NOT CLAY
 1304 IF(D10.GT.0.005) GO TO 1308
C     ------------------------------------------------------------------
C     STABILIZATION METHOD IS NOT ACCEPTABLE
 1305 MSTAC=2
C     CHECK IF USE CODE =4
      IF(MUST.EQ.4) GO TO 1306
      WRITE(LO,2315) NSSEG,NSHAFT
      GO TO 1310
 1306 ISTOP=1
      WRITE(LO,2320) NSSEG,NSHAFT
      GO TO 1310
C     ------------------------------------------------------------------
C     STABILIZATION METHOD IS ACCEPTABLE
 1308 MSTAC=1
 1310 B(I,28)=MSTAC
C     ------------------------------------------------------------------
C     CHECK FOR CORRECT GROUNDWATER CODE
  128 INFLOW=B(I,9)
      IF(INFLOW.EQ.0.OR.INFLOW.EQ.1) GO TO 129
      WRITE(LO,1047) NSSEG,NSHAFT
      ISTOP=1
C     ------------------------------------------------------------------
  129 IPS=NSHAFT
      GO TO 90
C     END OF SHAFT SEGMENT DATA
  130 CONTINUE
```

(Continued)

```
C
C      ****************************************************************
       NSS-I-1
C
C      ****************************************************************
C
C      READ SHAFT PROPERTIES
C
C      INITIALIZE SHAFT DATA ARRAY
       DO 132 I=1,NSMAX
       SHAFT(I,7)=-10.E30
  132  SHAFT(I,1)=-10.E30
C
  131  READ(LI,1025,ERR=450) NSHAFT,BFS,ISHAPS,DDS,CDS,AIRTEM,CFL,CFE,
      1CFM,RCF,HOURS,DAYS
       IF(NSHAFT.EQ.9999) GO TO 139
C      CHECK FOR PREVIOUS USE OF SHAFT NUMBER
  134  IF(SHAFT(NSHAFT,1).GT.-10.E29) WRITE(LO,1027) NSHAFT
       IF(SHAFT(NSHAFT,1).GT.-10.E29) ISTOP=1
C      IF SHAFT IS PORTAL,USER CAN OMIT BFS. SET SIZE
       NPORT=SHAFT(NSHAFT,23)
       IF(NPORT.EQ.1) BFS=20.
       SHAFT(NSHAFT,5)=DDS
       SHAFT(NSHAFT,6)=CDS
       SHAFT(NSHAFT,7)=BFS
       SHAFT(NSHAFT,11)=AIRTEM
       SHAFT(NSHAFT,12)=CFL
       SHAFT(NSHAFT,13)=CFE
       SHAFT(NSHAFT,14)=CFM
       SHAFT(NSHAFT,15)=RCF
       SHAFT(NSHAFT,16)=ISHAPS
       SHAFT(NSHAFT,17)=HOURS
       SHAFT(NSHAFT,18)=DAYS
C      ----------------------------------------------------------------
C      CHECK FOR FINISHED DIMENSION BETWEEN 10 AND 40 FEET
       IF(ISHAPS.GT.0.AND.BFS.LT.10..OR.ISHAPS.GT.0.AND.BFS.GT.40.)
      1WRITE(LO,1074) NSHAFT
C      ----------------------------------------------------------------
C      CHECK FOR PROPER SHAFT SHAPE CODE
       IF(ISHAPS.GE.0.AND.ISHAPS.LE.2) GO TO 135
       ISTOP=1
       WRITE(LO,2325) NSHAFT
  135  CONTINUE
C      ----------------------------------------------------------------
C      CHECK FOR SPECIFICATION OF PORTAL, BYPASS FOLLOWING CHECKS
       IF(NPORT.EQ.1) GO TO 136
C      ----------------------------------------------------------------
C      CHECK FOR SPECIFICATION OF DUMMY SHAFT
       IF(ISHAPS.EQ.0) WRITE(LO,2327) NSHAFT
C      ----------------------------------------------------------------
C      CHECK IF SHAPE CODE AGREES WITH INPUT SHAFT SIZE
       IF(BFS.EQ.0.AND.ISHAPS.EQ.0.OR.BFS.GT.0.AND.ISHAPS.GT.0) GO TO 136
       ISTOP=1
       IF(ISHAPS.EQ.0) WRITE(LO,2330) NSHAFT
       IF(ISHAPS.GT.0) WRITE(LO,2332) NSHAFT
  136  CONTINUE
C      ----------------------------------------------------------------
C      CHECK IF WORK HOURS PER DAY IN PROPER RANGE
```

(Continued)

```
      IF(HOURS.GE.0..AND.HOURS.LE.24.) GO TO 137
      ISTOP=1
      WRITE(LO,2335) NSHAFT
  137 CONTINUE
C     ------------------------------------------------------------------
C     CHECK IF WORK DAYS PER WEEK IN PROPER RANGE
      IF(DAYS.GE.4..AND.DAYS.LE.7..OR.DAYS.EQ.0.) GO TO 138
      ISTOP=1
      WRITE(LO,2340) NSHAFT
  138 CONTINUE
C     ------------------------------------------------------------------
      SHAFT(NSHAFT,1)=0.
      GO TO 131
C     END OF SHAFT PROPERTIES DATA
  139 CONTINUE
C     ******************************************************************
C
C
C     ------------------------------------------------------------------
C     MAKE SURE THAT ALL TUNNEL SEGMENTS HAVE REACHES DEFINED FOR THEM
      DO 200 I=1,NTS
      NTSEG=A(I,1)
      NREACH=A(I,4)
      IF(TRDATA(NREACH,1).GT.0.) GO TO 200
      ISTOP=1
      WRITE(LO,1200) NTSEG,NREACH
  200 CONTINUE
C     ------------------------------------------------------------------
C     CHECK THAT EVERY REACH NUMBER ASSIGNED HAS AT LEAST ONE TUNNEL
C     SEGMENT REFERRING TO IT
      DO 250 I=1,NTRMAX
      IF(TRDATA(I,1).LT.-10.E29) GO TO 250
      NREACH=I
      JJ=0
      DO 225 J=1,NTS
      IF(NREACH.EQ.A(J,4)) JJ=1
  225 CONTINUE
      IF(JJ.EQ.1) GO TO 250
      ISTOP=1
      WRITE(LO,1203) NREACH
  250 CONTINUE
C     ------------------------------------------------------------------
C     CHECK TO MAKE SURE ALL SHAFT SEGMENTS HAVE SHAFTS DEFINED FOR THEM
      DO 300 I=1,NSS
      NSSEG=B(I,2)
      NSHAFT=B(I,1)
      IF(SHAFT(NSHAFT,7).GT.-10.E29) GO TO 260
      ISTOP=1
      WRITE(LO,1201) NSSEG,NSHAFT
  260 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR PORTAL OR DUMMY SHAFT
      NPORT=SHAFT(NSHAFT,23)
      ISHAPS=SHAFT(NSHAFT,16)
      IF(NPORT.EQ.1.OR.ISHAPS.EQ.0) GO TO 300
C     ------------------------------------------------------------------
C     CHECK IF SHAPE CODE AGREES WITH SHAFT TYPE
      NSSTYP=B(I,15)
```

(Continued)

```
      IF(NSSTYP.GT.1.OR.ISHAPS.LT.2) GO TO 270
      ISTOP=1
      WRITE(LO,2345) NSSEG,NSHAFT
  270 CONTINUE
C     ---------------------------------------------------------------
C     CAST IRON SHAFT SUPPORT - CIRCULAR SHAFTS ONLY
      ISUPPT=B(I,22)
      IF(ISHAPS.EQ.1.OR.ISUPPT.NE.1.OR.NSSTYP.NE.2) GO TO 280
      ISTOP=1
      WRITE(LO,2350) NSSEG,NSHAFT
  280 CONTINUE
C     ---------------------------------------------------------------
C     IF THE SHAFT SEGMENT IS MOLED, ITS SHAPE MUST BE CIRCULAR
      MEX=B(I,7)
      IF(MEX.NE.2.AND.MEX.NE.3) GO TO 300
      IF(ISHAPS.EQ.1) GO TO 300
      ISTOP=1
      WRITE(LO,2355) NSSEG,NSHAFT
  300 CONTINUE
C     ---------------------------------------------------------------
C     CHECK THAT EVERY SHAFT NUMBER ASSIGNED HAS AT LEAST ONE SHAFT
C     SEGMENT REFERRING TO IT
      DO 350 I=1,NSMAX
      IF(SHAFT(I,1).LT.-10.E29) GO TO 350
      NSHAFT=I
      JJ=0
      DO 325 J=1,NSS
      IF(NSHAFT.EQ.B(J,1)) JJ=1
  325 CONTINUE
      IF(JJ.EQ.1) GO TO 350
      ISTOP=1
      WRITE(LO,1204) NSHAFT
  350 CONTINUE
C     ---------------------------------------------------------------
C     CHECK ALL REACHES TO MAKE SURE THAT THERE IS AN EXIT SHAFT DEFINED
      DO 400 I=1,NTRMAX
      IF(TRDATA(I,1).LT.-10.E29) GO TO 400
      NSHAFT=TRDATA(I,1)
      IF(SHAFT(NSHAFT,7).GT.-10.E29) GO TO 400
      ISTOP=1
      WRITE(LO,1202) I,NSHAFT
  400 CONTINUE
C     ---------------------------------------------------------------
C
C     CHECK FOR ANY STOPS  FOUND
  425 CONTINUE
      IF(ISTOP.EQ.0) GO TO 500
C     FATAL ERRORS DETECTED WHICH MAY MAKE FURTHER CALCULATIONS
C     MEANINGLESS. TERMINATE RUN AND GO TO NEXT SYSTEM DATA DECK
      WRITE(LO,1011)
      CALL NEXSET(LO,LI)
      RETURN
  450 WRITE (LO,1504)
      ISTOP = 1
      GO TO 425
C     IF NO FATAL ERRORS,LIST NODAL POINT DATA IF REQUESTED
  500 IF(LIST(1).EQ.1) RETURN
      WRITE(LO,1003)
```

(Continued)

```
      DO 600 I=1,NPMAX
  600 IF(CNP(I,2).GT.-10.E29) WRITE(LO,1004) I,CNP(I,2)
      RETURN
C
C
 1000 FORMAT(1X,I4,5X,F10.0)
 1001 FORMAT(/,' FATAL ERROR, NODAL POINT',I5,' MUST BE CHANGED TO A
     &NUMBER IN THE RANGE FROM 1 TO ',I4)
 1002 FORMAT(4I4,F5.0,I3,F7.0,F5.0,I3,F4.0,F7.0,2I3,F5.0)
 1003 FORMAT(///,10X,25H NODAL POINT    ELEVATION //)
 1004 FORMAT(10X,I7,8X,F9.2)
 1005 FORMAT(3F4.0,F8.0,F4.0,F7.0,F5.0,F3.0,F5.0,F7.0,F3.0,F6.0,F4.0,F2.
     10,F6.0,F3.0,F5.0)
 1006 FORMAT(4X,2F4.0,F8.0,F4.0,F7.0,F5.0,F3.0,F5.0,F7.0,F3.0,F6.0,F4.0,
     1F2.0,F6.0,F2.0,F1.0,F5.0)
 1007 FORMAT(4F4.0,8X,F8.0,F4.0,F3.0,F6.0,2F3.0,F6.0,F2.0,F6.0,F3.0,
     1F5.0)
 1008 FORMAT(16X,2F8.0,F4.0,F3.0,F6.0,2F3.0,F8.0,F6.0,F2.0,F1.0,F5.0)
 1011 FORMAT(///,1X,131('*'),/25X,'PROGRAM STOPPED BECAUSE OF ERRORS I
     1N SUBROUTINE INPUT ',/1X,131(1H*))
 1013 FORMAT(/,' FATAL ERROR, NODAL POINT',I5,' IS INPUTED ON TWO SEP
     1ARATE NODAL POINT CARDS')
 1015 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN REACH',I5,' IS OUT OF
     1SEQUENCE,CHECK DATA CARDS ARRANGEMENT OR FOR CORRECT NODAL POINT
     2S')
 1016 FORMAT(/,' FATAL ERROR, ALIGNMENT INCLUDES MORE THAN THE ',I4,'
     1 TUNNEL SEGMENTS ALLOWED')
 1017 FORMAT(/,' FATAL ERROR, ALIGNMENT INCLUDES MORE THAN THE ',I4,'
     1 SHAFT SEGMENTS ALLOWED')
 1020 FORMAT(2I4  ,F6.0,2I3  ,F5.0,F4.0,I3,2F5.0,I3,25X,I5)
 1021 FORMAT(/,' FATAL ERROR, REACH NUMBER',I5,' SHOULD BE CHANGED TO
     1 ONE IN THE RANGE OF 1 TO ',I5)
 1022 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' REFERS TO REACH',I5,' BU
     1T THIS REACH NUMBER HAS BEEN PREVIOUSLY ASSIGNED')
 1023 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' REFERS TO SHAFT',I5,' BU
     1T THIS SHAFT NUMBER HAS BEEN PREVIOUSLY ASSIGNED')
 1025 FORMAT(I4,F6.0,I3,F8.0,F7.0,F4.0,4F6.0,F5.0,F4.0)
 1026 FORMAT(/,' FATAL ERROR, DATA FOR REACH',I5,' HAVE BEEN SUPPLIED
     1 ON TWO SEPARATE REACH CARDS')
 1027 FORMAT(/,' FATAL ERROR, DATA FOR SHAFT',I5,' HAVE BEEN SUPPLIED
     1 ON TWO SEPARATE SHAFT CARDS')
 1029 FORMAT(/,' FATAL ERROR, EXCAVATION METHOD IN SEGMENT',I5,' IN SH
     1AFT',I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLANK),1,2,3,4')
 1030 FORMAT(/,' FATAL ERROR, EXCAVATION METHOD IN SEGMENT',I5,' IN RE
     1ACH', I5,' WAS NOT SPECIFIED BY USING CODE 1,2,3,4,5,6,OR 7')
 1031 FORMAT(/,' FATAL ERROR, ONE OR BOTH NODAL POINTS IN SEGMENT',I5,'
     1  IN REACH',I5,' WERE NOT LISTED WITH OTHER NODAL POINT DATA CARD
     2S')
 1034 FORMAT(/,' FATAL ERROR, SHAFT',I5,' LISTED WITH SHAFT SEGMENT',
     1I5,' IS NOT NUMBERED IN THE RANGE OF 1 TO ',I5)
 1040 FORMAT(/,' FATAL ERROR, CIRCULAR SHAPE WAS NOT SPECIFIED FOR MOL
     1ED EXCAVATION IN SEGMENT',I5,' IN REACH',I5)
 1041 FORMAT(/,' FATAL ERROR, MUCK TRANSPORT METHOD IN REACH',I5,' WA
     1S NOT SPECIFIED WITH A CODE OF ZERO(OR BLANK),1,2,3,OR 4')
 1042 FORMAT(/,' FATAL ERROR, TUNNEL SHAPE IN REACH',I5,' WAS NOT SPE
     1CIFIED WITH A CODE OF ZERO(OR BLANK),1,2,OR 3')
 1043 FORMAT(/,' FATAL ERROR, LINING TYPE IN SEGMENT',I5,' IN REACH',I5
     1,' WAS NOT SPECIFIED WITH A CODE OF ZERO(OR BLANK),1,2,OR 3')
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1045 FORMAT(/,' FATAL ERROR, A  LINING THICKNESS IS SPECIFIED FOR SEG
    1MENT',I4,' IN REACH',I4,',BUT NO LINING WAS SPECIFIED')
1046 FORMAT(/,' FATAL ERROR, A  LINING THICKNESS IS SPECIFIED FOR SEG
    1MENT',I4,' IN SHAFT',I4,',BUT NO LINING WAS SPECIFIED')
1047 FORMAT(/,' FATAL ERROR, GROUNDWATER INFLOW IN SEGMENT',I5,' IN S
    1HAFT',I5,' WAS NOT SPECIFIED WITH A CODE OF ZERO(OR BLANK) OR 1')
1048 FORMAT(/,' FATAL ERROR, LINING TYPE IN SEGMENT',I5,' IN SHAFT',I5
    1,' WAS NOT SPECIFIED WITH A CODE OF ZERO(OR BLANK),1,2,OR 3')
1055 FORMAT(/,' FATAL ERROR, SHAFT',I5,' IS NOT NUMBERED IN THE RANG
    1E OF 1 TO ',I5)
1060 FORMAT(/,' **** WARNING ****  ROCK STRENGTH IS LESS THAN 500 PSI
    1 IN SEGMENT',I5,' IN REACH',I5,' GETTING CLOSE TO SOFT GROUND',
    25X,14(1H*))
1062 FORMAT(/,' FATAL ERROR,  RQD IN SEGMENT',I5,' IN REACH',I5,
    1' IS NOT A NUMBER FROM 0 TO 100')
1064 FORMAT(/,' **** WARNING ****  TUNNEL SIZE IN REACH',I5,' IS NOT
    1 WITHIN THE RANGE OF 10 TO 40 FEET',5X,41(1H*))
1065 FORMAT(/,' FATAL ERROR, ADVANCE RATE IN SEGMENT',I5,' IN REACH',
    1 I5,' IS LESS THAN 0 FT/DAY')
1070 FORMAT(/,' **** WARNING ****  ROCK STRENGTH IS LESS THAN 500 PSI
    1 IN SEGMENT',I5,' IN SHAFT',I5,' GETTING CLOSE TO SOFT GROUND',
    25X,14(1H*))
1072 FORMAT(/,' FATAL ERROR,  RQD IN SEGMENT',I5,' IN SHAFT',I5,
    1 'IS NOT A NUMBER FROM  0 TO 100')
1074 FORMAT(/,' **** WARNING ****   SHAFT SIZE IN SHAFT',I5,' IS NOT
    1 WITHIN THE RANGE OF 10 TO 40 FEET',5X,41(1H*))
1075 FORMAT(/,' FATAL ERROR, ADVANCE RATE IN SEGMENT',I5,' IN SHAFT',
    1 I5,' IS LESS THAN 0 FT/DAY')
1115 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN SHAFT',I5,' IS OUT OF
    1SEQUENCE,CHECK DATA CARDS ARRANGEMENT OR FOR CORRECT NODAL POINT
    2S')
1131 FORMAT(/,' FATAL ERROR, ONE OR BOTH NODAL POINTS IN SEGMENT',I5,
    1' IN SHAFT',I5,' WERE NOT LISTED WITH OTHER NODAL POINT DATA CARD
    2S')
1200 FORMAT(/,' FATAL ERROR, TUNNEL SEGMENT',I5,' REFERS TO REACH',I5
    1,' BUT NO SUCH REACH HAS BEEN INPUTED')
1201 FORMAT(/,' FATAL ERROR, SHAFT  SEGMENT',I5,' REFERS TO SHAFT',I5
    1,' BUT NO SUCH SHAFT HAS BEEN INPUTED')
1202 FORMAT(/,' FATAL ERROR,  REACH',I5,' REFERS TO EXIT SHAFT',I5,
    1 ' BUT NO SUCH SHAFT HAS BEEN INPUTED')
1203 FORMAT(/,' FATAL ERROR, TUNNEL REACH',I5,' HAS BEEN ASSIGNED,BU
    1T NO TUNNEL SEGMENTS REFER TO IT')
1204 FORMAT(/,' FATAL ERROR, SHAFT',I5,' HAS BEEN ASSIGNED,BUT NO SH
    1AFT SEGMENTS REFER TO IT')
1500 FORMAT(/,' FATAL ERROR,NO SEPARATOR CARD AFTER NODAL POINT DATA')
1501 FORMAT(/,' FATAL ERROR, NO SEPARATOR CARD AFTER TUNNEL SEGMENT D
    1ATA',/25X,'-- OR --')
1502 FORMAT(/,' FATAL ERROR, NO SEPARATOR CARD AFTER TUNNEL REACH DAT
    1A')
1503 FORMAT(/,' FATAL ERROR, CHECK FOR MISSING SEPARATOR CARD AFTER S
    1HAFT SEGMENT DATA',/25X,'-- OR --')
1504 FORMAT(/,' FATAL ERROR, CHECK FOR MISSING SEPARATOR CARD AFTER S
    1HAFT DATA')
2000 FORMAT(/,' FATAL ERROR, TUNNEL TYPE IN SEGMENT',I5, ' IN REACH',
    1I5,' WAS NOT SPECIFIED BY USING CODE 1,2,OR 3')
2005 FORMAT(/,' FATAL ERROR, EXCAVATION METHOD IN SEGMENT',I5,' IN RE
    1ACH',I5,' DOES NOT MATCH TUNNEL TYPE SPECIFIED')
2010 FORMAT(/,' FATAL ERROR, LINING TYPE IN SEGMENT',I5,' IN REACH',
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     1I5,' DOES NOT MATCH TUNNEL TYPE SPECIFIED')
2015 FORMAT(/,' FATAL ERROR, WATERTIGHT LINING REQUIREMENT IN SEGMENT
     1,I5,' IN REACH',I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLA
     2NK) OR 1')
2017 FORMAT(/,' xxxx REMINDER xxxx   ALL CUT AND COVER TUNNEL SEGMEN
     1TS ARE DESIGNED AS WATERTIGHT -- INPUT IGNORED IN SEGMENT',I5,
     2' IN REACH',I5/20X,'AND WATERTIGHT DESIGN USED')
2020 FORMAT(/,' FATAL ERROR, NO LINING OR SUPPORT WAS SPECIFIED IN SE
     1GMENT',I5,' IN REACH',I5,' BUT A WATERTIGHT TUNNEL WAS SPECIFIED')
2025 FORMAT(/,' xxxx WARNING xxxx   GROUND WATER ELEVATION IN SEGMENT'
     1,I5,' IN REACH',I5,' IS EITHER ZERO OR BLANK - ELEVATION ZERO WI
     2LL BE USED IN',/' COMPUTATIONS',5X,114(1Hx))
2030 FORMAT(/,' FATAL ERROR, RQD IN SEGMENT',I5,' IN REACH',I5,' IS
     1LESS THAN 25 IN A ROCK TUNNEL. USE SOFT GROUND OR CUT AND COVER')
2035 FORMAT(/,' xxxx WARNING xxxx   RQD IN SEGMENT',I5,' IN REACH',I5,
     1' IS GREATER THAN 25 FOR A SOFT GROUND TUNNEL',5X,29(1Hx))
2040 FORMAT(/,' FATAL ERROR, SURFACE NODAL POINTS ABOVE SEGMENT',I5,
     1' IN REACH',I5,' ARE OUT OF SEQUENCE')
2045 FORMAT(/,' FATAL ERROR, ONE OR BOTH SURFACE NODAL POINTS ABOVE S
     1EGMENT',I5,' IN REACH',I5,' WERE NOT LISTED WITH OTHER NODAL POIN
     1T DATA CARDS')
2050 FORMAT(/,' FATAL ERROR,SURFACE NODAL POINT ELEVATIONS IN SEGMENT'
     1,I5,' IN REACH',I5,' ARE BELOW TUNNEL ELEVATION')
2055 FORMAT(/,' FATAL ERROR, EFFECTIVE GRAIN SIZE IN SEGMENT',I5,' IN
     1 REACH',I5,' WAS NOT INPUT')
2060 FORMAT(/,' FATAL ERROR, SOIL STRENGTH (PHI AND/OR COHESION) IN S
     1EGMENT',I5,' IN REACH',I5,' WAS NOT SPECIFIED')
2061 FORMAT(/,' xxxx WARNING xxxx   POSSIBLE ERROR IN PERMEABILITY IN
     1 SEGMENT',I5,' IN REACH',I5,' - INPUT IS GREATER THAN 10 CM/SEC',
     25X,12(1Hx))
2062 FORMAT(/,' xxxx WARNING xxxx   FRICTION ANGLE IN SEGMENT',I5,' I
     1N REACH',I5,' IS GREATER THAN 45 DEGREES',5X,35(1Hx))
2063 FORMAT(/,' FATAL ERROR, FRICTION ANGLE IN SEGMENT',I5,' IN REACH'
     1,I5,' IS GREATER THAN 100.CHECK FOR NUMBER SHIFTED ON DATA CARD')
2064 FORMAT(/,' FATAL ERROR, UNIT WEIGHT OF SOIL IN SEGMENT',I5,' IN
     1REACH',I5,' IS TOO LARGE FOR SOIL OR POOR ROCK')
2065 FORMAT(/,' FATAL ERROR, DEWATERING REQUIREMENT IN SEGMENT',I5,
     1' IN REACH',I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLANK)
     2OR 1')
2070 FORMAT(/,' xxxx WARNING xxxx   IMPERVIOUS LAYER ELEVATION IN SEG
     1MENT',I5,' IN REACH',I5,' IS EITHER ZERO OR BLANK - ELEVATION ZER
     2O WILL BE USED'/' IN COMPUTATIONS',5X,111(1Hx))
2072 FORMAT(/,' FATAL ERROR, IMPERVIOUS LAYER ELEVATION IN SEGMENT',
     1I5,' IN REACH',I5,' IS ABOVE AVERAGE SURFACE ELEVATION')
2073 FORMAT(/,' FATAL ERROR, IMPERVIOUS LAYER ELEVATION IN SEGMENT',
     1I5,' IN REACH',I5,' IS AT THE SURFACE AND SOIL GRAIN SIZE INPUT
     2EXCEEDS0.005')
2075 FORMAT(/,' FATAL ERROR, SUPPORT TYPE IN SOFT GROUND SEGMENT',
     1I5,' IN REACH',I5,' WAS NOT SPECIFIED BY CODE 1,2,3,4,5,OR 6')
2080 FORMAT(/,' FATAL ERROR, SUPPORT TYPE IN SEGMENT',I5,' IN REACH',
     1I5,' DOES NOT MATCH TUNNEL TYPE SPECIFIED')
2085 FORMAT(/,' FATAL ERROR, LINING TYPE IN SEGMENT',I5,' IN REACH',
     1I5,' DOES NOT MATCH SUPPORT TYPE SPECIFIED')
2090 FORMAT(/,' xxxx WARNING xxxx   ROCK ELEVATION IN SEGMENT',I5,
     1' IN REACH',I5,' IS EITHER ZERO OR BLANK - ELEVATION ZERO WILL B
     2E USED IN'/' COMPUTATIONS',5X,114(1Hx))
2092 FORMAT(/,' FATAL ERROR, ROCK ELEVATION IN SEGMENT',I5,' IN REACH'
     1,I5,' IS ABOVE AVERAGE SURFACE ELEVATION')
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2094 FORMAT(/,' **** WARNING ****   CUT AND COVER BOX IN SEGMENT',I5,    018230 0000
    1' IN REACH',I5,' EXCEEDS 100 FEET',5X,42(1H*))                      018240 0000
2095 FORMAT(/,' FATAL ERROR, OPEN CUT BRACING IN SEGMENT',I5,' IN REA    018250 0000
    1CH',I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLANK),1,2,OR 3')  018260 0000
2100 FORMAT(/,' FATAL ERROR, BRACING CODE FOR VERTICAL OPEN CUT IN SE    018270 0000
    1GMENT',I5,' IN REACH',I5,' WAS NOT SPECIFIED BY USING CODE 1,2,OR   018280 0000
    1 3')                                                                018290 0000
2105 FORMAT(/,' FATAL ERROR, DECKING CODE IN SEGMENT',I5,' IN REACH',    018300 0000
    1I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLANK) OR 1')          018310 0000
2115 FORMAT(/,' FATAL ERROR, STABILITY NUMBER IN SEGMENT',I5,' IN REA    018320 0000
    1CH',I5,' IS TOO HIGH, EXCAVATION IS IMPOSSIBLE')                    018330 0000
2120 FORMAT(/,' FATAL ERROR, STABILIZATION METHOD IN SEGMENT',I5,' IN    018340 0000
    1 REACH',I5,' WAS NOT SPECIFIED BY CODE ZERO(OR BLANK),1,2,OR 3')    018350 0000
2125 FORMAT(/,' FATAL ERROR, STABILIZATION USE CODE IN SEGMENT',I5,      018360 0000
    1' IN REACH',I5,' WAS NOT SPECIFIED BY CODE 1,2,3,OR 4')             018370 0000
2130 FORMAT(/,' FATAL ERROR, AIR PRESSURE IN SEGMENT',I5,' IN REACH',    018380 0000
    1I5,' WAS NOT SPECIFIED WHEN STABILITY NUMBER WAS INPUT AND AIR P    018390 0000
    2RESSURE'/' STABILIZATION SPECIFIED')                                018400 0000
2135 FORMAT(/,' FATAL ERROR, STABILITY NUMBER WAS SPECIFIED IN SEGMEN    018410 0000
    1T',I5,' IN REACH',I5,', BUT STABILIZATION USE CODE DOES NE 4')      018420 0000
2137 FORMAT(/,' FATAL ERROR, AIR PRESSURE IS SPECIFIED IN SEGMENT',I5,   018430 0000
    1' IN REACH',I5,' BUT STABILIZATION METHOD NOT COMPRESSED AIR')      018440 0000
2140 FORMAT(/,' FATAL ERROR, STABILIZATION USE CODE IN SEGMENT',I5,      018450 0000
    1' IN REACH',I5,' DOES NOT AGREE WITH METHOD SPECIFIED')             018460 0000
2145 FORMAT(/,' **** WARNING ****   STABILIZATION METHOD IN SEGMENT',    018470 0000
    1I5,' IN REACH',I5,' IS NOT ACCEPTABLE',5X,39(1H*))                  018480 0000
2147 FORMAT(/,' FATAL ERROR, INPUT IN SEGMENT',I5,' IN REACH',I5,        018490 0000
    1' REQUIRES USE OF AN UNACCEPTABLE STABILIZATION METHOD')            018500 0000
2150 FORMAT(/,' FATAL ERROR, TUNNEL SIZE IN REACH',I5,' INDICATES CU     018510 0000
    1T AND COVER SECTION, BUT SHAPE CODE IS NOT ZERO')                   018520 0000
2151 FORMAT(/,' FATAL ERROR, TUNNEL SHAPE IN REACH',I5,' INDICATES C     018530 0000
    1UT AND COVER SECTION, BUT SIZE IS SPECIFIED IN WRONG COLUMN')       018540 0000
2152 FORMAT(/,' FATAL ERROR, SHAPE IN REACH',I5,' INDICATES CUT AND      018550 0000
    1COVER, BUT A MUCK TRANSPORT METHOD WAS SPECIFIED')                  018560 0000
2153 FORMAT(/,' FATAL ERROR, TUNNEL REACH',I5,' IS NOT CUT AND COVER     018570 0000
    1, BUT NO MUCK TRANSPORT METHOD WAS SPECIFIED')                      018580 0000
2155 FORMAT(/,' FATAL ERROR, WORK HOURS IN REACH',I5,' WERE NOT SPEC     018590 0000
    1IFIED BY A NUMBER FROM0 TO 24')                                     018600 0000
2160 FORMAT(/,' FATAL ERROR, WORK DAYS IN REACH',I5,' WERE NOT SPECI     018610 0000
    1FIED BY A NUMBER FROM 4 TO 7')                                      018620 0000
2165 FORMAT(/,' FATAL ERROR, ONE OR BOTH BOX DIMENSIONS IN REACH',I5,    018630 0000
    1' WERE NOT INPUT')                                                  018640 0000
2170 FORMAT(/,' **** WARNING ****   TOTAL CLEAR BOX WIDTH IN REACH',     018650 0000
    1I5,' EXCEEDS 40 FEET',5X,55(1H*))                                   018660 0000
2175 FORMAT(/,' FATAL ERROR, OPEN CUT IS SPECIFIED IN REACH',I5,         018670 0000
    1' AND NUMBER OF BOX UNITS NOT SPECIFIED FOR A SINGLE LEVEL BOX')    018680 0000
2180 FORMAT(/,' **** WARNING ****   BOX HEIGHT IN REACH',I5,' IS GRE     018690 0000
    1ATER THAN 20 FEET FOR A SINGLE LEVEL BOX',5X,35(1H*))               018700 0000
2185 FORMAT(/,' **** WARNING ****   TOTAL CLEAR BOX HEIGHT IN REACH',    018710 0000
    1I5,' IS GREATER THAN 40 FEET FOR A DOUBLE BOX',5X,39(1H*))          018720 0000
2190 FORMAT(/,' **** WARNING ****   DEWATERING MAY BE USED AS A STABI    018730 0000
    1LIZATION METHOD IN SEGMENT',I5,' IN REACH',I5,' AND IMPERVIOUS LA   018740 0000
    2YER IS'/20X,' INCORRECTLY PLACED ABOVE THE TUNNEL. ELIMP WILL BE    018750 0000
    3ASSUMED AT TUNNEL INVERT.')                                         018760 0000
2195 FORMAT(/,' FATAL ERROR, COMPRESSED AIR WAS REQUIRED IN SEGMENT',    018770 0000
    1I5,' IN REACH',I5,' AND TRUCK MUCK TRANSPORT SPECIFIED')            018780 0000
2200 FORMAT(/,' FATAL ERROR, CAST IRON TUNNEL SUPPORT WAS SPECIFIED I    018790 0000
    1N SEGMENT',I5,' IN REACH',I5,', BUT CIRCULAR SHAPE NOT SPECIFIED')  018800 0000
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2201 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN REACH',I5,' IS NOT CUT
    1 AND COVER, BUT NO SHAPE WAS SPECIFIED')
2202 FORMAT(/,' FATAL ERROR, SHAPE SPECIFIED FOR SEGMENT',I5,' IN REA
    1CH',I5,' IS NOT FOR CUT AND COVER')
2203 FORMAT(/,' **** WARNING ****   SOUND ROCK ELEVATION LIES ABOVE B
    1ASE OF TRENCH IN SEGMENT',I5,' IN REACH',I5,' AND RQD IS BETWEEN
    225-50.'/20X,'RQD MAY BE TOO LOW FOR DESIGN AS SOUND ROCK.')
2204 FORMAT(/,' FATAL ERROR, SOUND ROCK ELEVATION LIES ABOVE BASE OF
    1 TRENCH IN SEGMENT',I5,' IN REACH',I5,' AND RQD IS LESS THAN 25.'/
    2 13X,' RQD IS TOO LOW FOR DESIGN AS SOUND ROCK')
2205 FORMAT(/,' FATAL ERROR, DEWATERING MUST BE ALLOWED IN SLOPING CU
    1T SEGMENT',I5,' IN REACH',I5,' BECAUSE WATER TABLE IS ABOVE BASE
    2OF TRENCH AND'/14X,' ABOVE IMPERVIOUS LAYER')
2207 FORMAT(/,' FATAL ERROR, SHAFT TYPE IN SEGMENT',I5,' IN SHAFT',I5,
    1' WAS NOT SPECIFIED BY USING CODE 1,2,OR 3')
2208 FORMAT(/,' **** WARNING *****   NO METHOD OF EXCAVATION OR LININ
    1G TYPE WERE INPUT FOR SEGMENT',I5,' IN SHAFT',I5,'. A DUMMY SHAFT
    2 IS ASSUMED')
2210 FORMAT(/,' FATAL ERROR, EXCAVATION METHOD IN SEGMENT',I5,' IN SH
    1AFT',I5,' DOES NOT MATCH SHAFT TYPE SPECIFIED')
2212 FORMAT(/,' FATAL ERROR, RQD IN SEGMENT',I5,' IN SHAFT',I5,' IS
    1LESS THAN 25 IN A ROCK SHAFT. USE SOFT GROUND OR CUT AND COVER')
2215 FORMAT(/,' **** WARNING ****   RQD IN SEGMENT',I5,' IN SHAFT',I5,
    1' IS GREATER THAN 25 FOR A SOFT GROUND SHAFT',5X,30(1H*))
2220 FORMAT(/,' FATAL ERROR, LINING TYPE IN SEGMENT',I5,' IN SHAFT',
    1I5,' DOES NOT MATCH SHAFT TYPE SPECIFIED')
2225 FORMAT(/,' FATAL ERROR, WATERTIGHT LINING REQUIREMENT IN SEGMENT'
    1,I5,' IN SHAFT',I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLA
    1NK) OR 1')
2227 FORMAT(/,' **** REMINDER ****   ALL CUT AND COVER SHAFT SEGMENT
    1S ARE DESIGNED AS WATERTIGHT -- INPUT IGNORED IN SEGMENT',I5,
    2' IN SHAFT',I5/20X,'AND WATERTIGHT DESIGN USED')
2230 FORMAT(/,' FATAL ERROR, NO LINING OR SUPPORT WAS SPECIFIED IN SE
    1GMENT',I5,' IN SHAFT',I5,' BUT A WATERTIGHT SHAFT WAS SPECIFIED')
2235 FORMAT(/,' **** WARNING ****   GROUND WATER ELEVATION IN SEGMENT'
    1,I5,' IN SHAFT',I5,' IS EITHER ZERO OR BLANK - ELEVATION ZERO WI
    2LL BE USED IN'/' COMPUTATIONS',5X,114(1H*))
2240 FORMAT(/,' FATAL ERROR, GROUND WATER ELEVATION LOCATED WITHIN SE
    1GMENT',I5,' IN SHAFT',I5,' - NEED TO DEFINE NEW SEGMENT AT GWT')
2245 FORMAT(/,' FATAL ERROR, EFFECTIVE GRAIN SIZE IN SEGMENT',I5,' IN
    1 SHAFT',I5,' WAS NOT INPUT')
2250 FORMAT(/,' FATAL ERROR, SOIL STRENGTH (PHI AND/OR COHESION) IN S
    1EGMENT',I5,' IN SHAFT',I5,' WAS NOT SPECIFIED')
2251 FORMAT(/,' **** WARNING ****   POSSIBLE ERROR IN PERMEABILITY IN
    1 SEGMENT',I5,' IN SHAFT',I5,' - INPUT IS GREATER THAN 10 CM/SEC',
    25X,12(1H*))
2252 FORMAT(/,' **** WARNING ****   FRICTION ANGLE IN SEGMENT',I5,' I
    1N SHAFT',I5,' IS GREATER THAN 45 DEGREES',5X,35(1H*))
2253 FORMAT(/,' FATAL ERROR, FRICTION ANGLE IN SEGMENT',I5,' IN SHAFT'
    1,I5,' IS GREATER THAN 100.CHECK FOR NUMBER SHIFTED ON DATA CARD')
2254 FORMAT(/,' FATAL ERROR, UNIT WEIGHT OF SOIL IN SEGMENT',I5,' IN
    1SHAFT',I5,' IS TOO LARGE FOR SOIL OR POOR ROCK')
2255 FORMAT(/,' FATAL ERROR, DEWATERING REQUIREMENT IN SEGMENT',I5,
    1' IN SHAFT',I5,' WAS NOT SPECIFIED BY USING CODE ZERO(OR BLANK)
    2OR 1')
2260 FORMAT(/,' **** WARNING ****   IMPERVIOUS LAYER ELEVATION IN SEG
    1MENT',I5,' IN SHAFT',I5,' IS EITHER ZERO OR BLANK - ELEVATION ZER
    20 WILL BE USED'/' IN COMPUTATIONS',5X,111(1H*))
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 2262 FORMAT(/,' FATAL ERROR, IMPERVIOUS LAYER ELEVATION IN SEGMENT',I5
     1,' IN SHAFT',I5,' IS ABOVE BASE OF SEGMENT. NEED TO DEFINE NEW I
     2MPERVIOUS'/' LAYER BELOW SEGMENT OR DEFINE NEW SEGMENT AT IMPERVI
     3OUS LAYER')
 2265 FORMAT(/,' FATAL ERROR, SUPPORT TYPE IN SOFT GROUND SEGMENT',I5,
     1' IN SHAFT',I5,' WAS NOT SPECIFIED BY CODE 1,2,3,4, OR 5')
 2270 FORMAT(/,' FATAL ERROR, SUPPORT TYPE IN SEGMENT',I5,' IN SHAFT',
     1I5,' DOES NOT MATCH SHAFT TYPE SPECIFIED')
 2275 FORMAT(/,' FATAL ERROR, LINING TYPE IN SEGMENT',I5,' IN SHAFT',
     1I5,' DOES NOT MATCH SUPPORT TYPE SPECIFIED')
 2285 FORMAT(/,' FATAL ERROR, STABILITY NUMBER IN SEGMENT',I5,' IN SHA
     1FT',I5,' IS TOO HIGH, EXCAVATION IS IMPOSSIBLE')
 2290 FORMAT(/,' FATAL ERROR, STABILIZATION METHOD IN SEGMENT',I5,' IN
     1 SHAFT',I5,' WAS NOT SPECIFIED BY CODE ZERO(OR BLANK),1,2,OR 3')
 2295 FORMAT(/,' FATAL ERROR, STABILIZATION USE CODE IN SEGMENT',I5,
     1' IN SHAFT',I5,' WAS NOT SPECIFIED BY CODE 1,2,3,OR 4')
 2300 FORMAT(/,' FATAL ERROR, AIR PRESSURE IN SEGMENT',I5,' IN SHAFT',
     1I5,' WAS NOT SPECIFIED WHEN STABILITY NUMBER WAS INPUT AND AIR P
     2RESSURE'/' STABILIZATION SPECIFIED')
 2305 FORMAT(/,' FATAL ERROR, STABILITY NUMBER WAS SPECIFIED IN SEGMEN
     1T',I5,' IN SHAFT',I5,' BUT STABILIZATION USE CODE DOES NE 4')
 2307 FORMAT(/,' FATAL ERROR, AIR PRESSURE IS SPECIFIED IN SEGMENT',I5,
     1' IN SHAFT', I5,' BUT STABILIZATION METHOD NOT COMPRESSED AIR')
 2310 FORMAT(/,' FATAL ERROR, STABILIZATION USE CODE IN SEGMENT',I5,
     1' IN SHAFT',I5,' DOES NOT AGREE WITH METHOD SPECIFIED')
 2315 FORMAT(/,' **** WARNING ****   STABILIZATION METHOD IN SEGMENT',
     1I5,' IN SHAFT',I5,' IS NOT ACCEPTABLE',30(1H*))
 2320 FORMAT(/,' FATAL ERROR, INPUT IN SEGMENT',I5,' IN SHAFT',I5,
     1' REQUIRES USE OF AN UNACCEPTABLE STABILIZATION METHOD')
 2325 FORMAT(/,' FATAL ERROR, SHAPE IN SHAFT',I5,' WAS NOT SPECIFIED
     1BY USING CODE ZERO(OR BLANK),1,OR 2')
 2327 FORMAT(/,' **** REMINDER ****   SHAFT',I5,' IS A DUMMY. IT HAS
     1NO CONSTRUCTION COST')
 2330 FORMAT(/,' FATAL ERROR, SHAFT SHAPE IN SHAFT',I5,' INDICATES A
     1DUMMY SHAFT, BUT A SIZE IS SPECIFIED')
 2332 FORMAT(/,' FATAL ERROR, SHAFT SIZE IN SHAFT',I5,' INDICATES A D
     1UMMY SHAFT, BUT SHAPE CODE IS NOT ZERO')
 2335 FORMAT(/,' FATAL ERROR, WORK HOURS IN SHAFT',I5,' WERE NOT SPEC
     1IFIED BY A NUMBER FROM0 TO 24')
 2340 FORMAT(/,' FATAL ERROR, WORK DAYS IN SHAFT',I5,' WERE NOT SPECI
     1FIED BY A NUMBER FROM 4 TO 7')
 2345 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN SHAFT',I5,' IS IN ROCK
     1 BUT SHAPE IS SQUARE')
 2350 FORMAT(/,' FATAL ERROR, CAST IRON SHAFT SUPPORT WAS SPECIFIED IN
     1 SEGMENT',I5,' IN SHAFT',I5,', BUT CIRCULAR SHAPE NOT SPECIFIED')
 2355 FORMAT(/,' FATAL ERROR, CIRCULAR SHAPE WAS NOT SPECIFIED FOR MOL
     1ED EXCAVATION IN SEGMENT',I5,' IN SHAFT',I5)
C     ------------------------------------------------------------------
C
C
      END
      SUBROUTINE SFTSET(A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
C     THIS SUBROUTINE WILL CREATE AN ARRAY CALLED SHAFT WHICH CONTAINS
C     PERTINENT SHAFT INFORMATION
```

(Continued)

```
C
C
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON /F/ IERROR,ISTOP
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ----------------------------------------------------------------
C
C     INITIALIZE
C
      NPT=B(1,3)
      NPB=B(1,4)
      NSEGS=0
      I=1
      NSSEG1=1
C     ----------------------------------------------------------------
C
   10 IP=I
      I=I+1
      NSEGS=NSEGS+1
C
C     CHECK FOR LAST SHAFT SEGMENT CARD
      IF(I.GT.NSS) GO TO 30
C
C     SEE IF PREVIOUS SEGMENT WAS IN SAME SHAFT AS THIS SEGMENT
      IF(B(I,1).EQ.B(IP,1)) GO TO 20
      GO TO 30
   20 NPB=B(I,4)
      GO TO 10
   30 NSHAFT=B(IP,1)
      SHAFT(NSHAFT,1)=NSSEG1
      SHAFT(NSHAFT,2)=NPT
      SHAFT(NSHAFT,3)=NPB
      SHAFT(NSHAFT,4)=NSEGS
      IF(I.GT.NSS) GO TO 40
      NPT=B(I,3)
      NPB=B(I,4)
      NSSEG1=I
      NSEGS=0
      GO TO 10
C     ----------------------------------------------------------------
   40 CONTINUE
C     CHECK FOR SHAFTS CONTAINING BOTH CUT AND COVER AND NON-CC SEGMENTS
      DO 800 NSHAFT=1,NSMAX
      IF(SHAFT(NSHAFT,1).LT.-10.E29) GO TO 800
      NSSEG1=SHAFT(NSHAFT,1)
      NSEGS=SHAFT(NSHAFT,4)
      DO 700 J=1,NSEGS
      NSSTYP=B(NSSEG1,15)
      IF(J.EQ.1) GO TO 700
      IF(NSSTYP.LT.3) GO TO 700
C     SEGMENT IS IN CUT AND COVER
      IF(NSSTYP.EQ.B(NSSEG1-1,15))GO TO 700
      ISTOP=1
      NSSEG=B(NSSEG1,2)
```

(Continued)

```
      WRITE(LO,1000) NSSEG,NSHAFT
  700 NSSEG1=NSSEG1+1
  800 CONTINUE
C     ------------------------------------------------------------------
C     CHECK FOR ANY STOPS FOUND
      IF(ISTOP.EQ.0) RETURN
C     FATAL ERRORS DETECTED.TERMINATE RUN AND GO TO NEXT DATA DECK
      WRITE(LO,2000)
      CALL NEXSET(LO,LI)
C     ------------------------------------------------------------------
 1000 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN SHAFT',I5,' IS IN CUT
     1AND COVER,BUT NOT ALL OTHER SEGMENTS ARE')
 2000 FORMAT(///,1X,119(1H*),/25X,'PROGRAM STOPPED BECAUSE OF ERRORS I
     1N SUBROUTINE SFTSET' ,/1X,119(1H*))
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
      RETURN
      END
```

(Continued)

```
      END
      SUBROUTINE LENGTH    (A,B,CNP,SHAFT,TRDATA,CUMSL,NTSMAX,NSSMAX,
     1NPMAX,NSMAX,NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     THIS SUBROUTINE CALCULATES ALL SEGMENT LENGHTS AND MUCK TRANSPORT
C     DISTANCES
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON /F/ IERROR,ISTOP
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23),CUMSL(NPMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CALCULATE SHAFT SEGMENT LENGTHS
      DO 20 I=1,NSS
      NPT=B(I,3)
      NPB=B(I,4)
      ELNPT=CNP(NPT,2)
      ELNPB=CNP(NPB,2)
      SSEGL=ELNPT-ELNPB
   20 B(I,35)=SSEGL
C     ------------------------------------------------------------------
C
C     CALCULATE SHAFT HOISTING DISTANCES FOR EACH SEGMENT AND EACH SHAFT
C     SUM .........RUNNING SUM OF SHAFT SEGMENT LENGTHS IN SHAFT I
C
      DO 50 I=1,NSMAX
      IF(SHAFT(I,1).LT.-10.E29) GO TO 50
      NSSEG1=SHAFT(I,1)
      NSEGS=SHAFT(I,4)
      SUM=0.
      DO 40 J=1,NSEGS
      SSEGL=B(NSSEG1,35)
      HH=SUM+.5*SSEGL
      B(NSSEG1,36)=HH
      SUM=SSEGL+SUM
   40 NSSEG1=NSSEG1+1
      SHAFT(I,8)=SUM
C     CHECK FOR SHAFT DEPTH GREATER THAN 3000 FEET
      IF(SHAFT( I,8).GT.3000.) WRITE(LO,1071) I
   50 CONTINUE
C     ------------------------------------------------------------------
C     CALCULATE ACTUAL TUNNEL SEGMENT LENGTH (LENGTH ALONG THE SEGMENT).
C     AS AN INTERMEDIATE STEP, CALCULATE THE STATIONING OF THE TUNNEL
C     NODAL POINTS ALONG THE LENGTH OF THE SEGMENTS (NOT THE HORIZONTAL
C     LENGTH), AND THEN CALCULATE HORIZONTAL STATIONING
C
      STA=STABEG
      NPL=A(1,2)
      CUMSL(NPL)=0.0
      CNP(NPL,1)=STABEG
      DO 60 I=1,NTS
      TSEGL=A(I,45)
```

(Continued)

```
      NPL=A(I,2)
      NPR=A(I,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
      SEGL=SQRT((ELNPL-ELNPR)**2+TSEGL**2)
      CUMSL(NPR)=CUMSL(NPL)+SEGL
      STA=STA+TSEGL
C     THE NEXT STATEMENT CONVERTS TSEGL FROM HORIZ. TO TRUE LENGTH
      TSEGL=SEGL
      A(I,45)=TSEGL
   60 CNP(NPR,1)=STA
C     ------------------------------------------------------------
C
C     CALCULATE AVERAGE MUCK TRANSPORTATION DISTANCES AND SLOPES (TO
C     MIDPOINT OF SEGMENTS) USING NODAL POINT STATIONING
C
      DO 70 I=1,NTS
      NPL=A(I,2)
      NPR=A(I,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
      NREACH=A(I,4)
      NSHAFT=TRDATA(NREACH,1)
      NPBS=SHAFT(NSHAFT,3)
      ELNPBS=CNP(NPBS,2)
      DM=ABS(CUMSL(NPBS)-(CUMSL(NPL)+CUMSL(NPR))/2.)/5280.
      RL=DM*5280.+ABS(CUMSL(NPL)-CUMSL(NPR))/2.
C     CHECK FOR REACH LENGTH GREATER THAN 105600 FEET( 20 MILES)
      IF(RL.GT.105600.) WRITE(LO,1061) NREACH
      A(I,46)=DM
C     CALCULATE ELEVATION DIFFERENCE FROM BASE OF SHAFT TO SEG. MIDPOINT
      ELEV=ELNPBS-(ELNPL+ELNPR)/2.
      HSLOPE=ELEV/SQRT((DM*5280.)**2-ELEV**2)
   70 A(I,47)=HSLOPE
C     ------------------------------------------------------------
C     CHECK FOR DUMMY SHAFT ADJACENT TO AT LEAST ONE CUT AND COVER REACH
      DO 200 I=1,NSMAX
      IF(SHAFT(I,1).LT.-10.E29) GO TO 200
      ISHAPS=SHAFT(I,16)
      IF(ISHAPS.NE.0) GO TO 200
      NPORT=SHAFT(I,23)
      IF(NPORT.EQ.1) GO TO 200
      NPBS=SHAFT(I,3)
      STA=CNP(NPBS,1)
      IF(STA.GT.STABEG) GO TO 100
      NTSTYP=A(1,16)
      IF(NTSTYP.EQ.3) GO TO 200
      GO TO 175
  100 STA=STA-1.0
      IJK=0
      DO 150 J=1,NTS
      NPL=A(J,2)
      NPR=A(J,3)
      IF(STA.GT.CNP(NPL,1).AND.STA.LT.CNP(NPR,1)) GO TO 160
  150 CONTINUE
  160 NTSTYP=A(J,16)
      IF(NTSTYP.EQ.3) GO TO 200
      IF(J.EQ.NTS) GO TO 175
```

(Continued)

```
      NTSTYP=A(J+1,16)
      IF(NTSTYP.EQ.3) GO TO 200
  175 IERROR=1
      WRITE(LO,2000) I
  200 CONTINUE
C     -----------------------------------------------------------------
 1061 FORMAT(/,' **** WARNING ****   TOTAL LENGTH OF REACH',I5,' EXCE
     1EDS 20 MILES',5X,51(1H*))
 1071 FORMAT(/,' **** WARNING ****   SHAFT',I5,' IS OVER 3000 FT DEEP'
     1,5X,63(1H*))
 2000 FORMAT(/,' FATAL ERROR, SHAFT',I5,' IS A DUMMY SHAFT, BUT THERE
     1 ARE NO ADJACENT CUT AND COVER REACHES')
      RETURN
      END
      SUBROUTINE INOUT(I,A,B,CNP,SHAFT,TRDATA,NLINES,IP,NTSMAX,NSSMAX,
     1NPMAX,NSMAX,NTRMAX)
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
C
C
C     THIS SUBROUTINE LISTS OUT THE INPUT DATA
C     SEGMENTS ARE LISTED IN THE ORDER OF APPEARANCE ALONG THE ROUTE
C
C     I= SEGMENT SEQUENCE NUMBER, NUMBER IN ORDER OF APPEARANCE
C
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
C
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
      DIMENSION FMT1(21),FMT2(15),FMT3(7),FMT4(20),FMT5(13)
C     *****************************************************************
C     DOUBLE PRECISION STATEMENTS ARE REQUIRED FOR LITERALS HAVING
C     5 TO 8 CHARACTERS ON COMPUTERS THAT HAVE 4 CHARACTERS PER WORD,
C     SUCH AS THE IBM 360, FORTRAN IV COMPILER.
C     REMOVE THE FOLLOWING DOUBLE PRECISION STATEMENTS FOR COMPUTERS
C     THAT HAVE  6 CHARACTERS PER WORD SUCH AS THE UNIVAC 1108,
C     FORTRAN V COMPILER.
C     ALL LITERALS IN THIS SUBROUTINE HAVE A MAXIMUM OF 6 CHARACTERS
C     TO BE COMPATABLE WITH BOTH SYSTEMS.
      DOUBLE PRECISION BLANK,CONV,TMOLER,TMOLES,HANDS,RIPPER,VERTCC,
     1SLOPCC,HORSE,BASKET,CIRCLE,BOX,TWOBOX,SQUARE,CONVYR,TRUCK,TRAIN,
     2CONTRK,TNONE,WET,DRY,ANO,YES,CIRSEG,CONSEG,STLSEG,STLSET,SOLDER,
     3SLURRY,OPENCT,AIRPRS,DEWATR,GRDINJ,USENO,PREFNO,STRUT,ANCHOR,
     4STRANC
      DOUBLE PRECISION SHAPE,REMK,EXCAV,WTLIN,AR,TL,HOURS,DAYS,SUPORT,
     1DWATER,STABIL,GAMMA,PERM,STABNO,AIRPR,DECK,BRACE,BFT,EXMS,
     2SHAPS,GRDW
      REAL*8  JBLANK,NONE,ISHOT,ICONC,IPREC,IFNEC,MUSTUS,IUSE,LTYP
C     *****************************************************************
      CHARACTER*6 FM1/'2X,A6,'/,FM2/'A5,'/,FM3/'A5)'/,FM4/
     1'(1X,A4'/,
     1FM5/'1X,A4,'/,FM6/'5X,A4,'/,FM7/'1X,A6,'/,FM8/'4X,A6,'/,FM9/'A6,'/
     2,FM10/'A6)'/,FM11/'(1X,I4'/,FM12/'F8.1,'/,FM13/'F5.1,'/,
     3FM14/'F5.1)'/,FM15/'I5,'/,FM16/'3X,I6,'/,FM17/'F7.1,'/,
     4FM18/'E10.2,'/,FM19/'F6.1,'/,FM20/'F6.1)'/,FM21/'F7.2,'/,
     5FM22/'3X,A4,'/,FM23/'I7,'/
```

(Continued)

```
      CHARACTER*6 FMT1/'(1X,I4','.I5,','I5,','I5,','I6,','I7,2X,','A6,',  022440 0000
     1'F7.2,'
     1,'2X,A6,','2X,A6,','F8.1,','3X,I6,','I5,','I5,','I5,','2X,A6,',     022450 0000
     2'F5.1,','A6,','F7.1,','F5.1,','F5.1)'/                              022460 0000
      CHARACTER*6 FMT2/'(10X,','I5,I5,','E10.2,','F7.1,', F5.0,',         022470 0000
     1'F7.0,',
     1 'E10.2,','I5,','A6,','F8.1,','2X,A6,','F6.1,','1X,A6,','1X,A6,',  022480 0000
     2'F6.1)'/                                                            022490 0000
      CHARACTER*6 FMT3/'(10X,','F7.1,','1X,A6,','2X,A6,','I5,','F8.2,'    022500 000
     1,'F7.2)'/
      CHARACTER*6 FMT4/'(1X,I4','.I5,','I5,','  I6,','2X,A6,','F6.2,',    022510 0000
     1'1X,A6,',
     1'F8.1,','3X,I6,','I5,','A6,','A6,','F6.1,','A6,','F7.1,','I8,',     022520 0000
     2'I7,','F9.1,','F6.1,','F5.1)'/                                      022530 0000
      CHARACTER*6 FMT5/'(20X,',  'F7.1,','F5.0,','F7.0,','E10.2,',        022540 0000
     1'E10.2,',
     1'4X,A6,','F8.1,','2X,A6,','F6.1,','2X,A6,','1X,A6,','F6.1)'/        022550 0000
C     ------------------------------------------------------------------- 022560 0000
      DATA BLANK/'      '/,JBLANK/'      '/,IBLANK/'    '/                022570 0000
      DATA  CONV/' CONV '/,TMOLER/'MOLER '/,TMOLES/'MOLES '/,HANDS/'HAND 022580 0000
     1S '/,RIPPER/'RIPPER'/,VERTCC/'VERTCC'/,SLOPCC/'SLOPCC'/             022590 0000
      DATA HORSE/'HORSE '/,BASKET/'BASKET'/,CIRCLE/'CIRCLE'/,BOX/'BOX    022600 0000
     1'/,TWOBOX/'TWOBOX'/,SQUARE/'SQUARE'/                                022610 0000
      DATA CONVYR/'CONVYR'/,TRUCK/'TRUCK '/,TRAIN/'TRAIN '/,CONTRK/'CONT 022620 0000
     1RK'/                                                                022630 0000
      DATA NONE/' NONE '/,TNONE/' NONE '/                                 022640 0000
      DATA ISHOT/' SHOT '/,ICONC/' CONC '/,IPREC/'PRECST'/                022650 0000
      DATA WET/'  WET '/,DRY/'  DRY '/                                    022660 0000
      DATA ANO/'  NO  '/,YES/'  YES '/                                    022670 0000
      DATA CIRSEG/'CIRSEG'/,CONSEG/'CONSEG'/,STLSEG/'STLSEG'/,STLSET/'S  022680 0000
     1TLSET'/,SOLDER/'SOLDER'/,SLURRY/'SLURRY'/,OPENCT/'OPENCT'/          022690 0000
      DATA AIRPRS/'AIRPRS'/,DEWATR/'DEWATR'/,GRDINJ/'GRDINJ'/             022700 0000
      DATA USENO/'NO USE'/,PREFNO/'NOPREF'/                               022710 0000
      DATA IFNEC/'IF NEC'/,MUSTUS/' MUST '/                               022720 0000
      DATA STRUT/'STRUT '/,ANCHOR/'ANCHOR'/,STRANC/'STRANC'/              022730 0000
C     ------------------------------------------------------------------- 022740 0000
      IF(ITYPE.EQ.2) GO TO 150                                            022750 0000
      IF(LIST(2).EQ.0) GO TO 10                                           022760 0000
C     SET VALUES OF GAMMA, PERM, HOURS AND DAYS IF NOT INPUT              022770 0000
      NREACH=A(I,4)                                                       022780 0000
      NTSTYP=A(I,16)                                                      022790 0000
      IF(NTSTYP.EQ.1) GO TO 5                                             022800 0000
      IF(A(I,22).LT.0.1) A(I,22)=120.                                     022810 0000
      IF(A(I,25).GT.10.E-10) PERM=-A(I,25)                                022820 0000
      D10=A(I,19)                                                         022830 0000
      IF(A(I,25).LT.10.E-10) PERM=D10**2/10.                              022840 0000
      A(I,25)=PERM                                                        022850 0000
    5 CONTINUE                                                            022860 0000
      IF(TRDATA(NREACH,8).LT.0.1) TRDATA(NREACH,8)=24.                    022870 0000
      IF(TRDATA(NREACH,9).LT.0.1) TRDATA(NREACH,9)=6.0                    022880 0000
      RETURN                                                              022890 0000
C                                                                         022900 0000
C                                                                         022910 0000
C     ------------------------------------------------------------------- 022920 0000
   10 NLINES=NLINES+1                                                     022930 0000
      IF(NLINES.LE.40) GO TO 30                                           022940 0000
C     WRITE OUT COLUMN HEADINGS FOR TUNNEL SEGMENTS                       022950 0000
C                                                                         022960 0000
```

(Continued)

```
      WRITE(LO,1000)
      WRITE(LO,1001)
      WRITE(LO,1002)
      NLINES=0
   30 NREACH=A(I,4)
      NTSEQ=A(I,1)
      NSHAFT=TRDATA(NREACH,1)
      BFT=TRDATA(NREACH,2)
      IPR=IP
C     ----------------------------------------------------------------
C     FIND THE HORIZONTAL SEGMENT LENGTH OF EACH SEGMENT, HSEGL,
C                  (HORIZONTAL SEGMENT LENGTH AS GIVEN IN THE INPUT
C         MUST BE CALCULATED SINCE IT WAS PREVIOUSLY DESTROYED WHEN
C           IT WAS CONVERTED TO LENGTH ALONG THE SEGMENT, TSEGL(I))
      NPL=A(I,2)
      NPR=A(I,3)
      SEGL=CNP(NPR,1)-CNP(NPL,1)
      LSEGL=SEGL
C     ----------------------------------------------------------------
C     FIND ALPHA NAME FOR SHAPE
   40 ISHAPE=TRDATA(NREACH,3)
      IBOX2=TRDATA(NREACH,13)
      IF(ISHAPE.EQ.0) SHAPE=BOX
      IF(ISHAPE.EQ.0.AND.IBOX2.EQ.1) SHAPE=TWOBOX
      IF(ISHAPE.EQ.1) SHAPE=CIRCLE
      IF(ISHAPE.EQ.2) SHAPE=HORSE
      IF(ISHAPE.EQ.3) SHAPE=BASKET
C     ----------------------------------------------------------------
C     FIND THE ALPHA NAME FOR THE LINING TYPE
      LINING=A(I,10)
      IF(LINING.EQ.0) LTYP=NONE
      IF(LINING.EQ.1) LTYP=ICONC
      IF(LINING.EQ.2) LTYP=ISHOT
      IF(LINING.EQ.3) LTYP=IPREC
      IF(LINING.EQ.4)LTYP=IPREC
C     ----------------------------------------------------------------
C     FIND ALPHA NAME FOR MUCK TRANSPORT METHOD
   50 MTM=TRDATA(NREACH,4)
      IF(MTM.EQ.1) REMK=TRUCK
      IF(MTM.EQ.2) REMK=CONVYR
      IF(MTM.EQ.3) REMK=TRAIN
      IF(MTM.EQ.4) REMK=CONTRK
C     ----------------------------------------------------------------
C     FIND ALPHA NAME FOR METHOD OF EXCAVATION
   60 MEX=A(I,7)
      IF(MEX.EQ.1) EXCAV=CONV
      IF(MEX.EQ.2) EXCAV=TMOLER
      IF(MEX.EQ.3) EXCAV=TMOLES
      IF(MEX.EQ.4) EXCAV=HANDS
      IF(MEX.EQ.5) EXCAV=RIPPER
      IF(MEX.EQ.6) EXCAV=VERTCC
      IF(MEX.EQ.7) EXCAV=SLOPCC
C     FIND ALPHA NAME FOR WATERTIGHT REQUIREMENT
      LINWT=A(I,15)
      IF(LINWT.EQ.0) WTLIN=ANO
      IF(LINWT.EQ.1) WTLIN=YES
      NTSTYP=A(I,16)
      IF(NTSTYP.EQ.3) WTLIN=YES
```

(Continued)

```
C     ----------------------------------------------------------------
   70 AR=A(I,8)
      JRS=A(I,5)
      JRQD=A(I,6)
      JRTEMP=A(I,12)
      INFLOW=A(I,9)
      IF(INFLOW.LT.0) INFLOW=0
      TL=A(I,11)
      IF(TL.LE.0.) TL=0.
      ELWATR=A(I,14)
      HOURS=TRDATA(NREACH,8)
      DAYS=TRDATA(NREACH,9)
C     ----------------------------------------------------------------
C     CHECK TO SEE IF THIS IS THE SAME REACH  AS FOR PREVIOUS SEGMENT
   85 IF(IPR.EQ.NREACH) GO TO 90
C     SET VALUES OF HOURS AND DAYS FOR PREVIOUS REACH IF NOT INPUT
      IF(I.EQ.1) GO TO 88
      N=A(I-1,4)
      IF(TRDATA(N,8).LT.0.1) TRDATA(N,8)=24.0
      IF(TRDATA(N,9).LT.0.1) TRDATA(N,9)=6.0
   88 WRITE(LO,1004)
   90 IF(IPR.EQ.NREACH) WRITE(LO,2000)
      NLINES=NLINES+1
C     ----------------------------------------------------------------
C     ADJUST FORMAT AND WRITE STATEMENTS TO PUT BLANKS IN OUTPUT WHEN
C     VARIABLE CHECKED IS NOT SPECIFIED IN INPUT DATA
   91 IF(AR.GT.0.0) GO TO 92
      AR=BLANK
      FMT1(11)=FM1
   92 IF(TL.GT.0.0) GO TO 93
      TL=BLANK
      FMT1(17)=FM2
   93 IF(HOURS.GT.0.0) GO TO 94
      HOURS=BLANK
      FMT1(20)=FM2
   94 IF(DAYS.GT.0.0) GO TO 95
      DAYS=BLANK
      FMT1(21)=FM3
   95 IF(IPR.NE.NREACH) GO TO 98
      NREACH=IBLANK
      FMT1(1)=FM4
      HOURS=BLANK
      FMT1(20)=FM2
      DAYS=BLANK
      FMT1(21)=FM3
   98 IF(NTSTYP.GT.1) GO TO 100
C     ----------------------------------------------------------------
C     ROCK TUNNEL
      WRITE(LO,FMT1) NREACH,NTSEG,NPL,NPR,NSHAFT,LSEGL,SHAPE,BFT,REMK,
     1EXCAV,AR,JRS,JRQD,JRTEMP,INFLOW,LTYP,TL,WTLIN,ELWATR,HOURS,DAYS
      GO TO 140
C     ----------------------------------------------------------------
C     SOFT GROUND TUNNEL OR CUT AND COVER BOX
C     FIND ALPHA NAME FOR SUPPORT TYPE
  100 ISUPPT=A(I,26)
      IF(ISUPPT.EQ.0) SUPORT=TNONE
      IF(ISUPPT.EQ.1) SUPORT=CIRSEG
      IF(ISUPPT.EQ.2) SUPORT=CONSEG
```

(Continued)

```
      IF(ISUPPT.EQ.3) SUPORT=STLSEG                                    024120 0000
      IF(ISUPPT.EQ.4) SUPORT=STLSET                                    024130 0000
      IF(ISUPPT.EQ.5) SUPORT=SOLDER                                    024140 0000
      IF(ISUPPT.EQ.6) SUPORT=SLURRY                                    024150 0000
C     FIND ALPHA NAME FOR ALLOWING DEWATERING                          024160 0000
      IWATER=A(I,23)                                                   024170 0000
      IF(IWATER.EQ.0) DWATER=ANO                                       024180 0000
      IF(IWATER.EQ.1) DWATER=YES                                       024190 0000
      NPLS=A(I,17)                                                     024200 0000
      NPRS=A(I,18)                                                     024210 0000
      D10=A(I,19)                                                      024220 0000
      PHI=0.0                                                          024230 0000
      COHESN=0.0                                                       024240 0000
      IF(A(I,20).GT.0.0) PHI=A(I,20)                                   024250 0000
      IF(A(I,21).GT.0.0) COHESN=A(I,21)                                024260 0000
      GAMMA=A(I,22)                                                    024270 0000
      ELIMP=A(I,24)                                                    024280 0000
      PERM=A(I,25)                                                     024290 0000
      STABNO=A(I,30)                                                   024300 0000
C     FIND ALPHA NAME FOR USE OF STABILIZATION METHOD                  024310 0000
      MUST=A(I,32)                                                     024320 0000
      IF(MUST.EQ.2)IUSE=IFNEC                                          024330 0000
      IF(MUST.EQ.3)IUSE=IFNEC                                          024340 0000
      IF(MUST.EQ.4)IUSE=MUSTUS                                         024350 0000
      AIRPR=A(I,33)                                                    024360 0000
C     FIND ALPHA NAME FOR STABILIZATION METHOD                         024370 0000
      MSTAB=A(I,31)                                                    024380 0000
      IF(MSTAB.EQ.0.AND.MUST.LE.2) STABIL=PREFNO                       024390 0000
      IF(MSTAB.EQ.0.AND.MUST.EQ.4) STABIL=USENO                        024400 0000
      IF(MSTAB.EQ.1) STABIL=AIRPRS                                     024410 0000
      IF(MSTAB.EQ.2) STABIL=DEWATR                                     024420 0000
      IF(MSTAB.EQ.3) STABIL=GRDINJ                                     024430 0000
C     ADJUST FORMAT AND WRITE STATEMENTS TO PUT BLANKS IN OUTPUT WHEN  024440 0000
C     VARIABLE CHECKED IS NOT SPECIFIED IN INPUT DATA                  024450 0000
C     DO NOT PRINT TEMPERATURE UNDER ROCK LISTING                      024460 0000
      JRTEMP=IBLANK                                                    024470 0000
      FMT1(14)=FM5                                                     024480 0000
  105 IF(JRS.GT.0) GO TO 106                                           024490 0000
      JRS=IBLANK                                                       024500 0000
      FMT1(12)=FM6                                                     024510 0000
  106 IF(JRQD.GT.0) GO TO 107                                          024520 0000
      JRQD=IBLANK                                                      024530 0000
      FMT1(13)=FM5                                                     024540 0000
  107 IF(GAMMA.GT.0.0) GO TO 108                                       024550 0000
      GAMMA=BLANK                                                      024560 0000
      FMT2(4)=FM7                                                      024570 0000
  108 IF(PERM.GT.0.0) GO TO 109                                        024580 0000
      PERM=BLANK                                                       024590 0000
      FMT2(7)=FM8                                                      024600 0000
  109 IF(STABNO.GT.0.0) GO TO 110                                      024610 0000
      STABNO=BLANK                                                     024620 0000
      FMT2(12)=FM9                                                     024630 0000
  110 IF(MUST.GT.1) GO TO 112                                          024640 0000
      IUSE=JBLANK                                                      024650 0000
  112 IF(AIRPR.GT.0.0) GO TO 118                                       024660 0000
      AIRPR=BLANK                                                      024670 0000
      FMT2(15)=FM10                                                    024680 0000
  118 IF(NTSTYP.EQ.3) GO TO 120                                        024690 0000
```

(Continued)

```
C     ----------------------------------------------------------------
C     SOFT GROUND TUNNEL
      WRITE(LO,FMT1) NREACH,NTSEG,NPL,NPR,NSHAFT,LSEGL,SHAPE,BFT,REMK,
     1EXCAV,AR,JRS,JROD,JRTEMP,INFLOW,LTYP,TL,WTLIN,ELWATR,HOURS,DAYS
      JRTEMP=A(I,12)
      WRITE(LO,FMT2) NPLS,NPRS,D10,GAMMA,PHI,COHESN,PERM,JRTEMP,DWATER,
     1ELIMP,SUPORT,STABNO,STABIL,IUSE,AIRPR
      NLINES=NLINES+1
      GO TO 140
C     ----------------------------------------------------------------
C     CUT AND COVER
C     FIND ALPHA NAMES FOR DECKING REQUIREMENT
  120 IDECK=A(I,29)
      IF(IDECK.EQ.0) DECK=ANO
      IF(IDECK.EQ.1) DECK=YES
C     FIND ALPHA NAME FOR BRACING SPECIFIED
      IBRACE=A(I,28)
      IF(IBRACE.EQ.0) BRACE=TNONE
      IF(IBRACE.EQ.1) BRACE=STRUT
      IF(IBRACE.EQ.2) BRACE=ANCHOR
      IF(IBRACE.EQ.3) BRACE=STRANC
      ELROCK=A(I,27)
      NREACH=A(I,4)
      NBOX=TRDATA(NREACH,10)
      BFBWDT=TRDATA(NREACH,11)
      BFBHT=TRDATA(NREACH,12)
C     ADJUST FORMAT AND WRITE STATEMENTS TO PUT BLANKS IN OUTPUT WHEN
C     VARIABLE CHECKED IS NOT SPECIFIED IN INPUT DATA
C     REMOVE TUNNEL SIZE, MUCK TRANSPORT, SOIL TEMPERATURE, AND
C     STABILIZATION FOR CUT AND COVER.
      IF(IPR.EQ.NREACH) NREACH=IBLANK
      BFT=BLANK
      FMT1(8)=FM7
      REMK=BLANK
      JRTEMP=IBLANK
      FMT2(8)=FM5
      IF(INFLOW.GT.0) GO TO 138
      INFLOW=IBLANK
      FMT1(15)=FM5
      STABIL=BLANK
  138 WRITE(LO,FMT1) NREACH,NTSEG,NPL,NPR,NSHAFT,LSEGL,SHAPE,BFT,REMK,
     1EXCAV,AR,JRS,JROD,JRTEMP,INFLOW,LTYP,TL,WTLIN,ELWATR,HOURS,DAYS
      WRITE(LO,FMT2) NPLS,NPRS,D10,GAMMA,PHI,COHESN,PERM,JRTEMP,DWATER,
     1ELIMP,SUPORT,STABNO,STABIL,IUSE,AIRPR
      WRITE(LO,FMT3) ELROCK,DECK,BRACE,NBOX,BFBWDT,BFBHT
      NLINES=NLINES+2
C     ----------------------------------------------------------------
  140 NREACH=A(I,4)
      IF(IPR.NE.NREACH) IPR=NREACH
C     SET VALUE FOR GAMMA IN THIS TUNNEL SEGMENT IF NOT INPUT
      IF(NTSTYP.GT.1.AND.A(I,22).LT.0.1) A(I,22)=120.0
C     SET VALUE FOR PERMEABILITY IF NOT INPUT
      IF(NTSTYP.GT.1.AND.A(I,25).GT.10.E-10) PERM=-PERM
      IF(NTSTYP.GT.1.AND.A(I,25).LT.10.E-10) PERM=D10**2/10.
      A(I,25)=PERM
      IP=IPR
C     RESET FORMATS TO ORIGINAL IN DATA STATEMENT
      FMT1(1)=FM11
```

(Continued)

```
      FMT1(11)=FM12
      FMT1(17)=FM13
      FMT1(20)=FM13
      FMT1(21)=FM14
      IF(NTSTYP.EQ.1) GO TO 145
      FMT1(14)=FM15
      FMT1(12)=FM16
      FMT1(13)=FM15
      FMT2(4)=FM17
      FMT2(7)=FM18
      FMT2(12)=FM19
      FMT2(15)=FM20
      IF(NTSTYP.EQ.2) GO TO 145
      FMT1(8)=FM21
      FMT2(8)=FM15
      FMT1(15)=FM15
  145 CONTINUE
      IF(I+1.LE.NTS) RETURN
C     SET HOURS AND DAYS FOR LAST REACH IF NOT INPUT
      IF(TRDATA(NREACH,8).LT.0.1)  TRDATA(NREACH,8)=24.0
      IF(TRDATA(NREACH,9).LT.0.1)  TRDATA(NREACH,9)=6.0
      WRITE(LO,1004)
      RETURN
C
C     ******************************************************************
C     ******************************************************************
C     ******************************************************************
C     ******************************************************************
C
  150 IF(LIST(3).EQ.0) GO TO 200
C     SET VALUES OF GAMMA, PERM, HOURS AND DAYS IF NOT INPUT
      NSHAFT=B(I,1)
      NSSTYP=B(I,15)
      IF(NSSTYP.EQ.1) GO TO 160
      IF(B(I,18).LT.0.1) B(I,18)=120.
      IF(B(I,23).GT.10.E-10) PERM=-B(I,23)
      D10=B(I,16)
      IF(B(I,23).LT.10.E-10) PERM=D10**2/10.
      B(I,23)=PERM
  160 CONTINUE
      IF(SHAFT(NSHAFT,17).LT.0.1) SHAFT(NSHAFT,17)=24.
      IF(SHAFT(NSHAFT,18).LT.0.1) SHAFT(NSHAFT,18)=6.0
      RETURN
C     WRITE OUT THE DATA CONCERNING THE SHAFTS
C
C
C     ------------------------------------------------------------------
  200 NLINES=NLINES+1
      IF(NLINES.LE.45) GO TO 230
C
      WRITE(LO,1010)
      WRITE(LO,1011)
      NLINES=0
  230 NSHAFT=B(I,1)
      NSSEG=B(I,2)
      BFS=SHAFT(NSHAFT,7)
      NPT=B(I,3)
      NPB=B(I,4)
```

(Continued)

```
      NPORT=SHAFT(NSHAFT,23)
      NPTS=SHAFT(NSHAFT,2)
      NPBS=SHAFT(NSHAFT,3)
      JRS=B(I,5)
      JRQD=B(I,6)
      NSSTYP=B(I,15)
      IPS=IP
C     ------------------------------------------------------------------
C     FIND THE ALPHA NAME FOR THE LINING TYPE
      LINING=B(I,10)
      IF(LINING.EQ.0) LTYP=NONE
      IF(LINING.EQ.1) LTYP=ICONC
      IF(LINING.EQ.2) LTYP=ISHOT
      IF(LINING.EQ.3) LTYP=IPREC
C     ------------------------------------------------------------------
C     FIND ALPHA NAME FOR EXCAVATION METHOD
  240 MEX=B(I,7)
      IF(MEX.EQ.0) EXMS=TNONE
      IF(MEX.EQ.1) EXMS=CONV
      IF(MEX.EQ.2) EXMS=TMOLER
      IF(MEX.EQ.3) EXMS=TMOLES
      IF(MEX.EQ.4) EXMS=HANDS
C     FIND ALPHA NAME FOR SHAFT SHAPE
      ISHAPS=SHAFT(NSHAFT,16)
      IF(ISHAPS.EQ.1) SHAPS=CIRCLE
      IF(ISHAPS.EQ.2) SHAPS=SQUARE
C     FIND ALPHA NAME FOR WATERTIGHT REQUIREMENT
      LINWT=B(I,14)
      IF(LINWT.EQ.0) WTLIN=ANO
      IF(LINWT.EQ.1) WTLIN=YES
      IF(NSSTYP.EQ.3) WTLIN=YES
      ELWATR=B(I,13)
      HOURS=SHAFT(NSHAFT,17)
      DAYS=SHAFT(NSHAFT,18)
C     ------------------------------------------------------------------
      AR=B(I,8)
C     FIND ALPHA NAME FOR SHAFT GROUNDWATER INFLOW
      INFLOW=B(I,9)
      IF(INFLOW.EQ.1) GRDW=WET
      IF(INFLOW.EQ.0) GRDW=DRY
C     ------------------------------------------------------------------
      TL=B(I,11)
      IF(TL.LE.0.) TL=0.
      DDS=SHAFT(NSHAFT,5)
      IARTEM=SHAFT(NSHAFT,11)
  260 ICDS=SHAFT(NSHAFT,6)
C     ------------------------------------------------------------------
C     SEE IF THE SHAFT FOR THIS SEGMENT IS SAME AS PREVIOUS SHAFT
  285 IF(IPS.EQ.NSHAFT) GO TO 290
C     SET VALUES OF HOURS AND DAYS FOR PREVIOUS SHAFT IF NOT INPUT
      IF(I.EQ.1) GO TO 288
      N=B(I-1,1)
      IF(SHAFT(N,17).LT.0.1) SHAFT(N,17)=24.0
      IF(SHAFT(N,18).LT.0.1) SHAFT(N,18)=6.0
  288 WRITE(LO,1004)
  290 IF(IPS.EQ.NSHAFT) WRITE(LO,2000)
      NLINES=NLINES+1
C     CHECK FOR PORTAL
```

(Continued)

```
      IF(NPORT.EQ.0) GO TO 292
      WRITE(LO,8200) NSHAFT,NPTS,DDS,ICDS,IARTEM
      GO TO 350
C     ------------------------------------------------------------------
C     DUMMY SHAFT IS INPUT WHEN NO SHAFT IS REQUIRED FOR OPEN CUT REACH
  292 IF(ISHAPS.NE.0) GO TO 300
      WRITE(LO,2100) NSHAFT,NSSEG,NPTS,NPBS,DDS,ICDS,IARTEM
      GO TO 350
C     ------------------------------------------------------------------
C     ADJUST FORMAT AND WRITE STATEMENTS TO PUT BLANKS IN OUTPUT WHEN
C     VARIABLE CHECKED IS NOT SPECIFIED IN INPUT DATA
  300 IF(AR.GT.0.0) GO TO 301
      AR=BLANK
      FMT4(8)=FM1
  301 IF(TL.GT.0.0) GO TO 302
      TL=BLANK
      FMT4(13)=FM9
  302 IF(HOURS.GT.0.0) GO TO 303
      HOURS=BLANK
      FMT4(19)=FM9
  303 IF(DAYS.GT.0.0) GO TO 305
      DAYS=BLANK
      FMT4(20)=FM3
  305 IF(IPS.NE.NSHAFT) GO TO 308
      NSHAFT=IBLANK
      FMT4(1)=FM4
      HOURS=BLANK
      FMT4(19)=FM9
      DAYS=BLANK
      FMT4(20)=FM3
  308 IF(NSSTYP.GT.1) GO TO 310
C     ------------------------------------------------------------------
C     ROCK SHAFT
      WRITE(LO,FMT4) NSHAFT,NSSEG,NPT,NPB,SHAPS,BFS,EXMS,AR,JRS,JRGD,
     1GRDW,LTYP,TL,UTLIN,DDS,ICDS,IARTEM,ELWATR,HOURS,DAYS
      GO TO 350
C     ------------------------------------------------------------------
C     SOFT GROUND SHAFT OR CUT AND COVER
C     FIND ALPHA NAME FOR ALLOWING DEWATERING
  310 IWATER=B(I,21)
      IF(IWATER.EQ.0) DWATER=ANO
      IF(IWATER.EQ.1) DWATER=YES
C     FIND ALPHA NAME FOR SUPPORT TYPE
      ISUPPT=B(I,22)
      IF(ISUPPT.EQ.1) SUPORT=CIRSEG
      IF(ISUPPT.EQ.2) SUPORT=CONSEG
      IF(ISUPPT.EQ.3) SUPORT=STLSEG
      IF(ISUPPT.EQ.4) SUPORT=STLSET
      IF(ISUPPT.EQ.5) SUPORT=OPENCT
      D10=B(I,16)
      GAMMA=B(I,18)
      PHI=0.0
      COHESN=0.0
      IF(B(I,19).GT.0.0) PHI=B(I,19)
      IF(B(I,17).GT.0.0) COHESN=B(I,17)
      PERM=B(I,23)
      ELIMP=B(I,20)
      STABNO=B(I,24)
```

(Continued)

```
C     FIND ALPHA NAME FOR USE OF STABILIZATION METHOD
      MUST=B(I,26)
      IF(MUST.EQ.2)IUSE=IFNEC
      IF(MUST.EQ.3)IUSE=IFNEC
      IF(MUST.EQ.4)IUSE=MUSTUS
      AIRPR=B(I,27)
C     FIND ALPHA NAME FOR STABILIZATION METHOD
      MSTAB=B(I,25)
      IF(MSTAB.EQ.0.AND.MUST.LE.2) STABIL=PREFNO
      IF(MSTAB.EQ.0.AND.MUST.EQ.4) STABIL=USENO
      IF(MSTAB.EQ.1) STABIL=AIRPRS
      IF(MSTAB.EQ.2) STABIL=DEWATR
      IF(MSTAB.EQ.3) STABIL=GRDINJ
C     ADJUST FORMAT AND WRITE STATEMENTS TO PUT BLANKS IN OUTPUT WHEN
C     VARIABLE CHECKED IS NOT SPECIFIED IN INPUT DATA
      IF(GAMMA.GT.0.0) GO TO 320
      GAMMA=BLANK
      FMT5(3)=FM7
  320 IF(PERM.GT.0.0) GO TO 321
      PERM=BLANK
      FMT5(6)=FM8
  321 IF(STABNO.GT.0.0) GO TO 322
      STABNO=BLANK
      FMT5(10)=FM9
  322 IF(MUST.GT.1) GO TO 324
      IUSE=JBLANK
  324 IF(AIRPR.GT.0.0) GO TO 325
      AIRPR=BLANK
      FMT5(13)=FM10
  325 IF(JRS.GT.0) GO TO 326
      JRS=IBLANK
      FMT4(9)=FM6
  326 IF(JRQD.GT.0) GO TO 329
      JRQD=IBLANK
      FMT4(10)=FM5
  329 IF(NSSTYP.EQ.3) GO TO 330
C     ------------------------------------------------------------------
C     SOFT GROUND SHAFT
      WRITE(LO,FMT4) NSHAFT,NSSEG,NPT,NPB,SHAPS,BFS,EXMS,AR,JRS,JRQD,
     1GRDW,LTYP,TL,WTLIN,DDS,ICDS,IARTEM,ELWATR,HOURS,DAYS
      WRITE(LO,0006) D10,GAMMA,PHI,COHESN,PERM,DWATER,ELIMP,SUPORT,
     1STABNO,STABIL,IUSE,AIRPR
      NLINES=NLINES+1
      GO TO 350
C     ------------------------------------------------------------------
C     CUT AND COVER
C     SHAFT IS BUILT WITHIN OPEN CUT CONSTRUCTED FOR TUNNEL
C     ADJUST FORMAT AND WRITE STATEMENTS TO PUT BLANKS IN OUTPUT WHEN
C     VARIABLE CHECKED IS NOT SPECIFIED IN INPUT DATA
C     REMOVE VARIABLES THAT DO NOT APPLY TO CUT AND COVER
```

(Continued)

```
C     QRDU,IARTEM,DWATER,ELIMP,STABIL
  330 QRDU=BLANK
      IARTEM=IBLANK
      FMT4(17)=FM22
      DWATER=BLANK
      ELIMP=BLANK
      FMT5(8)=FM1
      STABIL=BLANK
      WRITE(LO,FMT4) NSHAFT,NSSEG,NPT,NPB,SHAPS,BFS,EXMS,AR,JRS,JRQD,
     1QRDU,LTYP,TL,UTLIN,DDS,ICDS,IARTEM,ELWATR,HOURS,DAYS
      WRITE(LO,0006) D10,GAMMA,PHI,COHESN,PERM,DWATER,ELIMP,SUPORT,
     1STABNO,STABIL,IUSE,AIRPR
      NLINES=NLINES+1
C     ------------------------------------------------------------
  350 NSHAFT=B(I,1)
      IF(IPS.NE.NSHAFT) IPS=NSHAFT
C     SET VALUE FOR GAMMA IN THIS SHAFT SEGMENT IF NOT INPUT
      IF(NSSTYP.GT.1.AND.B(I,18).LT.0.1) B(I,18)=120.0
      IF(NSSTYP.GT.1.AND.B(I,23).GT.10.E-10) PERM=-PERM
      IF(NSSTYP.GT.1.AND.B(I,23).LT.10.E-10) PERM=D10**2/10.
      B(I,23)=PERM
      IP=IPS
C     RESET FORMATS TO ORIGINAL IN DATA STATEMENT
      FMT4(1)=FM11
      FMT4(8)=FM12
      FMT4(13)=FM19
      FMT4(19)=FM19
      FMT4(20)=FM14
      IF(NSSTYP.EQ.1) GO TO 360
      FMT5(3)=FM17
      FMT5(6)=FM18
      FMT5(10)=FM19
      FMT5(13)=FM20
      FMT4(9)=FM16
      FMT4(10)=FM15
      IF(NSSTYP.EQ.2) GO TO 360
      FMT4(17)=FM23
      FMT5(8)=FM12
  360 CONTINUE
      IF(I+1.LE.NSS) RETURN
C     SET HOURS AND DAYS FOR LAST SHAFT IF NOT INPUT
      IF(SHAFT(NSHAFT,17).LT.0.1) SHAFT(NSHAFT,17)=24.0
      IF(SHAFT(NSHAFT,18).LT.0.1) SHAFT(NSHAFT,18)=6.0
      WRITE(LO,1004)
C
-
```

(Continued)

```
C     ******************************************************************
      RETURN
C
C     ******************************************************************
C
 1000 FORMAT(1H1,49(1H*),'  T U N N E L  I N P U T  D A T A  ',47(1H*)//
     11X,'REACH SEG NP BOUNDRY EXIT  HORIZ  TUNNEL TUNNEL  MUCK    EXCAU
     2A- UNF ADU *ROCK PROPERTIES* INFLOW *** LINING **** GROUND HOURS D
     3AYS'/11X,'LEFT RIGHT SHAFT LENGTH  SHAPE  SIZE  REMOVAL   TION
     4RATE   STRENGTH RQD TEMP  (GPM) TYPE  THICK WAT WATER   PER  PER '
     5/43X,'(FT)   METHOD  METHOD (FT/DAY)  (PSI)',7X,'(F)',15X,'(IN)  T
     6GT ELEV.   DAY  WEEK')
 1001 FORMAT(33(2X,2H--)/13X,'SURFACE   ',12(1H*),' SOIL PROPERTIES ',13(
     11H*),' DEWAT- IMPERV SUPPORT ***** STABILIZATION *****'/11X,'NP BO
     2UNDRY GRN SIZE UNIT WT PHI COHESION  PERM.  TEMP ERING  LAYER    TY
     3PE   NUMBER METHOD  USE  AIRPR'/11X,'LEFT RIGHT  (M M)    (PCF)
     4     (PSF)  (CM/SEC) (F)  ALLOW  ELEV.',30X,'(PSI)')
 1002 FORMAT(33(2X,2H--)/11X,'SOUND  *CUT AND COVER* **BOX PROPERTIES**'
     1/11X,'ROCK   DECKING BRACING UNITS WIDTH HEIGHT'/11X,'ELEV.',25X,
     2'(FT)  (FT)'//)
 1004 FORMAT(1X,131(1H-))
 1010 FORMAT(1H1,50(1H*),'  S H A F T  I N P U T  D A T A  ',48(1H*)//
     11X,'SHAFT SEG NP BOUNDARY  SHAFT SHAFT EXCAVA- UNF ADV *ROCK PROP.
     2* INFLOW *** LINING **** DISPOSAL DISPOSAL ABOVE GROUND  HOURS DAY
     3S'/11X,'UPPER LOWER  SHAPE  SIZE  TION    RATE   STRENGTH RQD
     4   TYPE  THICK WAT DISTANCE   COST   GRND. WATER    PER  PER'/31X,
     5'(FT) METHOD (FT/DAY)  (PSI)',20X,'(IN)  TGT  (MILES) ($/ACRE) TEM
     6P  ELEV.    DAY  WEEK')
 1011 FORMAT(33(2X,2H--)/22X,11(1H*),' SOIL PROPERTIES ',10(1H*),'   DEW
     1AT-   IMPERV SUPPORT ***** STABILIZATION *****'/22X,'GRN SIZE UNIT
     2 WT PHI COHESION  PERM.     ERING    LAYER  TYPE   NUMBER METHOD
     3 USE  AIRPR'/23X,'(M M)    (PCF)        (PSF)  (CM/SEC)    ALLOW
     4 ELEV.',30X,'(PSI)'//)
 2000 FORMAT(1X)
 2100 FORMAT(1X,I4,I5,I5,I6,10X,'THIS SHAFT IS A DUMMY',36X,F7.1,I8,I7)
 2200 FORMAT(I5,14X,'THIS SHAFT  AT NODAL POINT',I4,'  IS ACTUALLY A
     1PORTAL',14X,F10.1,I8,I7)
 0001 FORMAT(/,1X,I4,I5,I5,I5,I6,I7,2X,A6,F7.2,2X,A6,2X,A6,F8.1,3X,I6,
     1I5,I5,I5,2X,A6,F5.1,A6,F7.1,F5.1,F5.1,/)
 0002 FORMAT(/ 10X,I5,I5,E10.2,F7.1,F5.0,F7.0,E10.2,I5,A6,F8.1,2X,A6,
     1F6.1,1X,A6,1X,A6,F6.1,/)
 0003 FORMAT(/,10X,F7.1,1X,A6,2X,A6,I5,F8.2,F7.2,/)
 0004 FORMAT(/,1X,I4,I5,I5,I6,2X,A6,F6.2,1X,A6,F8.1,3X,I6,I5,A6,A6,F6.1,
     1A6,F7.1,I8,I7,F9.1,F6.1,F5.1,/)
 0006 FORMAT(/,20X,E10.2,F7.1,F5.0,F7.0,E10.2,4X,A6,F8.1,2X,A6,F6.1,2X,
     1A6,1X,A6,F6.1,/)
      END
```

(Continued)

```
      SUBROUTINE SIZEST(I,A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX
     1,NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     I=TUNNEL OR SHAFT SEGMENT NUMBER
C     THIS SUBROUTINE CALCULATES THE FOLLOWING IN TUNNELS OR SHAFTS
C     BE,BE40,BE60,TL,BOB,BOB40,BOB60,WEB,TPLATE,TSEG,DTRNCH,SIDEL,WBOX,
C     TWOL,FORMAR,WTWALE,WTSTRT,WTANCH,WTSP,WTSPD
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
C     ******************************************************************
C     GENERAL DATA
C     ******************************************************************
C
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
      REAL MIN,MAX
C
C     I=TUNNEL SEGMENT SEQUENCE NUMBER
C
C     ITYPE=1 INDICATES TUNNEL SEGMENT
      ITYPE=1
      NREACH=A(I,4)
      NTSEG=A(I,1)
      TLIN=A(I,11)
      BFT=TRDATA(NREACH,2)
      BF=BFT
      LINING=A(I,10)
      MEX=A(I,7)
      ISHAPE=TRDATA(NREACH,3)
      MSTAKE=0
      ELWATR=A(I,14)
      NPL=A(I,2)
      NPR=A(I,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
      ELAVG=(ELNPL+ELNPR)/2.
      LINWT=A(I,15)
      NTSTYP=A(I,16)
      NSSTYP=0
      GO TO 10
C
```

(Continued)

```
C     -----------------------------------------------------------------
C
      ENTRY SIZESS(I,A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     I=SHAFT SEGMENT SEQUENCE NUMBER
C     ITYPE=2 INDICATES SHAFT SEGMENT
      ITYPE=2
      TLIN=B(I,11)
      NSHAFT=B(I,1)
      ISHAPS=SHAFT(NSHAFT,16)
      IF(ISHAPS.EQ.0) RETURN
      NPORT=SHAFT(NSHAFT,23)
      IF(NPORT.EQ.1) RETURN
      NSSEG=B(I,2)
      BFS=SHAFT(NSHAFT,7)
      BF=BFS
      LINING=B(I,10)
      MEX=B(I,7)
      MSTAKE=0
      ELWATR=B(I,13)
      LINWT=B(I,14)
      NSSTYP=B(I,15)
      NTSTYP=0
      NPT=B(I,3)
      NPB=B(I,4)
      ELNPT=CNP(NPT,2)
      ELNPB=CNP(NPB,2)
      ELAVG=(ELNPT+ELNPB)/2.
C
C
C     -----------------------------------------------------------------
C
C     CONVERT TL TO FEET
   10 TLIN=TLIN/12.
C     IS IT A ROCK TUNNEL OR SHAFT
      IF(NTSTYP.EQ.1.OR. NSSTYP.EQ.1) GO TO 15
C     IS IT A SHAFT
      IF(ITYPE.EQ.2) GO TO 12
      PHI=A(I,20)
      NPLS=A(I,17)
      NPRS=A(I,18)
      ELNPLS=CNP(NPLS,2)
      ELNPRS=CNP(NPRS,2)
      ELSURF=(ELNPLS+ELNPRS)/2.
      GAMMA=A(I,22)
      COHESN=A(I,21)
      ISUPPT=A(I,26)
      GO TO 13
   12 PHI=B(I,19)
      GAMMA=B(I,18)
      COHESN=B(I,17)
      ISUPPT=B(I,22)
      NPTS=SHAFT(NSHAFT,2)
      ELSURF=CNP(NPTS,2)
   13 PI=3.14159
      DWATER=ELSURF-ELWATR
      ICUTNC=0
C     IS IT A SOFT GROUND TUNNEL OR SHAFT
```

(Continued)

```
      IF(NTSTYP.EQ.2 .OR. NSSTYP.EQ.2) GO TO 1000
      GO TO 2900
C
C
C
C     ****************************************************************
C     ROCK TUNNEL OR SHAFT
C     ****************************************************************
C
C     II IS A FLOW INDICATOR
   16 II=4
C     ----------------------------------------------------------------
C     LINING FOR WATER PRESSURE
C     ----------------------------------------------------------------
      PWATER=62.4*(ELWATR-ELAVG)
      IF(ITYPE.EQ.1) RQD=A(I,6)
      IF(ITYPE.EQ.2) RQD=B(I,6)
      WEB =0.
C     IF THE WATER LOAD IS ZERO, ASSIGN PWATER=0.001 FOR ESTIMATING
C     LINING THICKNESS ( ZERO VALUE MAY MAKE RESULT INDEFINITE )
      IF(PWATER.LE.0.001) PWATER=0.001
      IF(LINWT.EQ.0) PWATER=0.001
      IF(ITYPE.EQ.2) GO TO 21
      GO TO(21,22,23),ISHAPE
   21 TL=0.5*BF*PWATER/(288000.-PWATER)
      GO TO 30
   22 TL=0.77E-10*BF**0.86*PWATER**1.9*EXP(SQRT((16.9-1.42*ALOG(PWATER))
     1**2+0.32))
      GO TO 30
   23 TL=3.8E-7*(7.+4.6*BF)*PWATER**1.035*EXP(SQRT((6.5-0.565*ALOG
     1(PWATER))**2+0.17))
C     SET MIN. CONCRETE THICKNESS TO BE 8 INCHES. IF SHOTCRETE
C     THICKNESS NOT INPUT, SET MIN. TO BE 3 INCHES
   30 IF(LINING.EQ.1 .AND. TL.LT.0.6666) TL=0.6666
      IF(LINING.EQ.2.AND.TLIN.LT.0.001.AND.TL.LT.0.25) TL=0.25
C     ----------------------------------------------------------------
C     FLOW CONTROLED BY RQD VALUE
C     ----------------------------------------------------------------
      IF(RQD.GE.60.) GO TO 200
      IF(RQD.LE.40.) GO TO 100
C     RQD LIES BETWEEN 40 AND 60,INTERPOLATION OF SIZES IS NECESSARY.
C     SIZE WILL BE COMPUTED FOR RQD=40 AND RQD=60 BEFORE INTERPOLATING
C     TO OBTAIN SIZE AT ACTUAL RQD
      II=1
C     STORE THE ACTUAL VALUES OF LINING THICKNESS AND RQD
      RQDD=RQD
      TT=TL
C     ASSIGN A FICTICIOUS RQD FOR THE FIRST PART OF INTERPOLATION COMP
      RQD=40
C     ----------------------------------------------------------------
C      RQD IS 40 OR LESS
C     ----------------------------------------------------------------
C     HAS A LINING THICKNESS BEEN INPUT.   IF SO,COMPUTE AND STORE
C     EXCAVATED DIMENSION USING THIS THICKNESS
C     CHECK FOR CIRCULAR SHAPE
  100 IF(ISHAPE.EQ.1)  GO TO (110,120),MEX
C     SHAPE IS HORSESHOE OR BASKETHANDLE
C     COMPUTE DEPTH OF STEEL RIB SUPPORT
```

(Continued)

```
      WEB   =(0.294*BF+3.35 )/12.
      GO TO 145
C     CONVENTIONAL EXCAVATION
  110 WEB   =(0.254*BF+0.17-0.064*RQD)/12.
      GO TO 130
C     MOLE EXCAVATION
  120 WEB   =(0.207*BF+0.138-0.052*RQD)/12.
  130 IF(WEB*12..LT.4.0) WEB    =4./12.
C     IS SEGMENT LINED OR UNLINED
  145 IF(LINING.GT.0) GO TO 150
C     NO LINING
      BE=BF+WEB*2.
      TL=0.0
      GO TO 400
C     LINED
C     CHECK FOR LINING TYPE
  150 IF(LINING.EQ.1) GO TO 170
C     CALCULATE EXCAVATED DIMENSION FOR SHOTCRETE
      IF(TLIN.GT.0.001) GO TO 160
C     CHECK IF RIB  THICKNESS + 3 IN. .GE. THE LINING THICKNESS
  152 IF(WEB     +0.25 .GE. TL) GO TO 155
      BE=BF+2.*TL
      GO TO 400
  155 BE=BF+WEB*2.+0.5
      GO TO 400
C     CHECK IF THE GIVEN LINING THICKNESS .LT. THAT FOR WATER PRESSURE
  160 IF(TLIN.LT.TL) MSTAKE=2
      IF(TLIN.LT.TL) GO TO 152
      TL=TLIN
  165 IF(WEB     +0.25.GE.TL) GO TO 155
      BE=BF+2.*TLIN
      GO TO 400
C     CONCRETE
  170 TLMIN=WEB     +0.333
      IF(TL.LT.TLMIN) TL=TLMIN
C     WAS A LINING THICKNESS INPUT
      IF(TLIN.GT.0.001) GO TO 175
  174 BE=BF+2.*TL
      GO TO 400
C     CHECK IF THE GIVEN LINING THICKNESS .GE. MINIMUM DIM. REQUIRED
  175 IF(TLIN.GE.TLMIN) GO TO 176
C     ERROR - TL INPUT IS NOT THICK ENOUGH, PRINT WARNING
C     WAS THIS A TUNNEL OR SHAFT
      IF(ITYPE.EQ.1) WRITE(LO,1010) NTSEG,NREACH
      IF(ITYPE.EQ.2) WRITE(LO,1011) NSSEG,NSHAFT
      MSTAKE=1
      GO TO 174
C     CHECK IF THE GIVEN LINING THICKNESS .LT. THAT FOR WATER PRESSURE
  176 IF(TLIN.LT.TL) GO TO 177
      BE=BF+2.*TLIN
      TL=TLIN
      GO TO 400
  177 MSTAKE=2
      GO TO 174
C
C     ------------------------------------------------------------------
C     RQD IS GREATER THAN OR EQUAL TO 60
C     ------------------------------------------------------------------
```

(Continued)

```
C     HAS A LINING THICKNESS BEEN INPUT
  200 IF(TLIN.GT.0.001) GO TO 230
C     IS SEGMENT LINED OR UNLINED
      IF(LINING.GT.0)GO TO 216
C     UNLINED
      TL=0.0
      BE=BF
      GO TO 400
  216 BE=BF+2.*TL
      GO TO 400
C     LINING TYPE
  230 IF(LINING.EQ.2) GO TO 250
C     CONCRETE
      IF(TLIN.LT.0.666) GO TO 260
      GO TO 250
C     INPUT ERROR - TL INPUT IS NOT THICK ENOUGH, USE TL=0.667
C     IF ERROR MESSAGE WAS ALREADY PRINTED,SKIP IT NOW
  260 IF(MSTAKE.EQ.1) GO TO 216
      IF(ITYPE.EQ.1) WRITE(LO,1010) NTSEG,NREACH
      IF(ITYPE.EQ.2) WRITE(LO,1011) NSSEG,NSHAFT
      GO TO 216
C     CHECK IF THE GIVEN LINING THICKNESS .LT. THAT FOR WATER PRESSURE
  250 IF(TLIN.LT.TL) GO TO 275
      BE=BF+2.*TLIN
      TL=TLIN
      GO TO 400
  275 MSTAKE=2
      GO TO 216
C     ---------------------------------------------------------------
C     OVERBREAK DIMENSION
C     ---------------------------------------------------------------
C     WHAT IS THE EXCAVATION METHOD
  400 IF(MEX.EQ.2) BOB=BE
      IF(MEX.EQ.1) BOB=BE+(250.-RQD)*(BE+10.)/2500.
C
C     ---------------------------------------------------------------
C     RQD BETWEEN 40 AND 60
C     ---------------------------------------------------------------
      IF(II.LT.3) GO TO 450
      BE40=BE
      BE60=BE
      BOB40=BOB
      BOB60=BOB
      GO TO 600
  450 IF(II.GE.2) GO TO 500
C     STORE BE AND BOB COMPUTED USING FICTICIOUS RQD=40
      BE40=BE
      BOB40=BOB
C     REDEFINE RQD TO A FICTICIOUS VALUE OF 60 FOR SECOND PART OF
C     INTERPOLATION COMPUTATION
      RQD=60.
C     RE-ESTABLISH INPUT   VALUE OF LINING THICKNESS FOR PURPOSES OF
C     THE CHECK IN STATEMENT 200
      TL=TT
C     REDEFINE FLOW INDICATOR
      II=II+1
      GO TO 200
C
```

(Continued)

```
C     -----------------------------------------------------------------
C     STORE BE AND BOB COMPUTED USING FICTICIOUS RQD=60
  500 BE60=BE
      BOB60=BOB
C
C     CALCULATE BE AND BOB BY INTERPOLATING BETWEEN BE AND BOB
C     VALUES AT RQD=40 AND RQD=60
C
      BE=BE40+(RQDD-40.)/20.*(BE60-BE40)
      BOB=BOB40+(RQDD-40.)/20.*(BOB60-BOB40)
C
  550 IF(LINING.NE.1) GO TO 600
C     COMPUTE THE AVERAGE THICKNESS FOR THE CONCRETE LINING
C     WHEN THE RQD IS BETWEEN 40 AND 60
      TL=(BE-BF)/2.
C
C
C     -----------------------------------------------------------------
C     SET VARIABLES FOR SHAFT OR TUNNEL SEGMENTS
C     -----------------------------------------------------------------
  600 IF(ITYPE.EQ.2) GO TO 700
C     TUNNEL SEGMENT DATA
      A(I,39)=BE
      A(I,40)=BE40
      A(I,41)=BE60
      A(I,42)=BOB
      A(I,43)=BOB40
      A(I,44)=BOB60
      A(I,62)=WEB
      A(I,64)=PWATER
      A(I,11) = TL
      IF(MSTAKE.EQ.2) WRITE(LO,2710) NTSEG,NREACH
      GO TO 4000
C
C     SHAFT SEGMENT DATA
  700 B(I,29)=BE
      B(I,30)=BE40
      B(I,31)=BE60
      B(I,32)=BOB
      B(I,33)=BOB40
      B(I,34)=BOB60
      B(I,41)=WEB
      B(I,43)=PWATER
      B(I,11) = TL
      IF(MSTAKE.EQ.2) WRITE(LO,2711) NSSEG,NSHAFT
      GO TO 4000
C
C
C     *****************************************************************
C     SOFT GROUND TUNNELS AND SHAFTS
C     *****************************************************************
 1000 BE=BF
      N=0
      I2=0
      TANPHI=TAN(PHI*PI/180.)
C     -----------------------------------------------------------------
C     MINIMUM SUPPORT SIZE
C     -----------------------------------------------------------------
```

(Continued)

```
      GO TO(1001,1002,1003,1005),ISUPPT
C     CAST IRON SEGMENTED SUPPORT
 1001 TSEGMN=0.6666
      TPLMIN=0.05
      FF=4
      GO TO 1004
C     PRECAST CONCRETE SEGMENTED SUPPORT
 1002 TSEGMN=1
      TPLMIN=0.125
      FF=2
      GO TO 1004
C     STEEL SEGMENTED SUPPORT
 1003 TSEGMN=0.583
      TPLMIN=0.03
      FF=4
 1004 IF(TLIN.GT.0. .AND. TLIN.LT.TPLMIN) GO TO 1008
      IF(TLIN.GT.TPLMIN) GO TO 1025
      GO TO 1009
 1025 IF(ELWATR.LT.ELAVG .OR. LINWT.EQ.0) GO TO 1026
      GO TO 1009
C     WHEN WATER PRESSURE=0, INPUT  LINER THICKNESS GREATER THAN MINIMUM
C     VALUE WILL BE ACCEPTED
 1026 I2=1
      TPLATE=TLIN
      GO TO 2354
C     STEEL SEGMENTED SUPPORT
 1005 IF(LINING.EQ.2) GO TO 1006
      TLMIN=0.6666
      IF(TLIN.GT.0. .AND. TLIN.LT.TLMIN) GO TO 1008
      GO TO 1009
 1006 TLMIN=0.333
      IF(TLIN.GT.0.) TLMIN=0
      GO TO 1009
C     INPUT   LINER OR LINING THICKNESS LESS THAN MINIMUM VALUE
 1008 MSTAKE=1
C     ------------------------------------------------------------
C     UNIT WEIGHT OF SOIL
C     ------------------------------------------------------------
 1009 BBEE=BE
      N=N+1
      SEGDEP=ELSURF-ELAVG
C     CHECK FOR GWT ABOVE GROUND SURFACE
      IF(ELWATR.GT.ELSURF) GO TO 1045
C     CHECK FOR SEGMENT BELOW GWT
      IF(ELAVG.LT.ELWATR) GO TO 1015
C     GWT IS BELOW SEGMENT
      SIGGAH=SEGDEP*GAMMA
      IF(SEGDEP.LE.2.*BE) GO TO 1012
      GAMMAA=GAMMA
      GAMMAB=GAMMA
      GO TO 1050
 1012 GAMMAC=GAMMA
      GO TO 1050
C     SEGMENT IS BELOW GWT
 1015 SIGGAH=DWATER*GAMMA+(ELWATR-ELAVG)*(GAMMA-62.4)
      IF(SEGDEP.LE.2.*BE) GO TO 1030
      IF(DWATER.GT.2.*BE) GO TO 1020
C     SEGMENT IS DEEPER THAN 2BE AND GWT IS WITHIN 2BE OF GROUND SURFACE
```

(Continued)

```
      GAMMAA=(GAMMA*DWATER+(GAMMA-62.4)*(2.*BE-DWATER))/(2.*BE)
      GAMMAB=(GAMMA-62.4)
      GO TO 1050
C     SEGMENT AND GWT ARE BOTH DEEPER THAN 2BE
 1020 GAMMAA=GAMMA
      GAMMAB=(GAMMA*(DWATER-2.*BE)+(GAMMA-62.4)*(ELWATR-ELAVG))
     1/(SEGDEP-2.*BE)
      GO TO 1050
C     SEGMENT IS WITHIN 2BE OF GROUND SURFACE
 1030 GAMMAC=(GAMMA*DWATER+(GAMMA-62.4)*(ELWATR-ELAVG))/SEGDEP
      GO TO 1050
C     GWT IS ABOVE GROUND SURFACE
 1045 GAMMAA=GAMMA-62.4
      GAMMAB=GAMMA-62.4
      GAMMAC=GAMMA-62.4
      SIGGAH=SEGDEP*(GAMMA-62.4)
C     ADJUST UNIT WEIGHTS OF SOIL FOR DRAINED SEGMENT
 1050 IF(LINWT.EQ.1) GO TO 1100
      GAMMAA=GAMMA
      GAMMAB=GAMMA
      GAMMAC=GAMMA
C     ------------------------------------------------------------------
C     EXPRESS SOIL STRENGTH IN TERMS OF EQUIVALENT PHI
C     ------------------------------------------------------------------
 1100 PHIEQR=ATAN(COHESN/SIGGAH+TANPHI)
      PHIEQ=PHIEQR*180./PI
      IF(PHIEQ.GT.45.) PHIEQ=45.
C     ------------------------------------------------------------------
C     TUNNEL AND SHAFT LOADS
C     ------------------------------------------------------------------
C     ESTABLISH SEGMENT TYPE AND SHAPE FACTORS
      IF(SEGDEP.LE.2.*BE) GO TO 1300
      F=1.0
      FSHAPE=1.0
      IF(ITYPE.EQ.1) GO TO 1110
C     SHAFT SEGMENT
      F=0.5
      FSHAPE=0.5
      IF(ISHAPS.EQ.2) F=0.6
      IF(ISHAPS.EQ.2) FSHAPE=0.6
      GO TO 1200
C     TUNNEL SEGMENT
 1110 IF(ISHAPE.EQ.3) FSHAPE=1.25
C     ------------------------------------------------------------------
 1200 PSOIL=2.*BE*GAMMAA*F+(SEGDEP-2.*BE)*(0.34-PHIEQ**2./6000.)*
     1 GAMMAB*FSHAPE
      GO TO 1310
 1300 F=1.0
      IF(ITYPE.EQ.1) GO TO 1301
C     SHAFT SEGMENT
      F=0.5
      IF(ISHAPS.EQ.2) F=0.6
 1301 PSOIL=SEGDEP*GAMMAC*F
C     ------------------------------------------------------------------
 1310 IF(LINWT.EQ.1) GO TO 1320
C     DRAINED
      PWATER=0
      GO TO 1330
```

(Continued)

```
C     WATERTIGHT
 1320 PWATER=62.4*(ELWATR-ELAVG)
C     OUT BELOW SEGMENT
      IF(PWATER.LT.0.) PWATER=0
 1330 IF(ISUPPT.LE.3 .AND. TLIN.GT.TPLMIN) GO TO 1331
      PTOTAL=PSOIL+PWATER
      GO TO 2000
C     INPUT   LINER THICKNESS GREATER THAN MINIMUM VALUE WILL BE CHECKED
C     FOR WATER PRESSURE
 1331 PTOTAL=PWATER
C     IF PSOIL, PWATER, OR PTOTAL EQUAL 0, THEN ASSIGN A VALUE OF 0.001
C     FOR ESTIMATING SUPPORT SIZE
 2000 IF(PSOIL.LT.0.001) PSOIL=0.001
      IF(PWATER.LT.0.001) PWATER=0.001
      IF(PTOTAL.LT.0.001) PTOTAL=0.001
C     ------------------------------------------------------------------
C     SUPPORT SIZE
C     ------------------------------------------------------------------
      GO TO(2100,2200,2300,2400),ISUPPT
C     CAST IRON SEGMENTED SUPPORT
 2100 TPLATE=7.E-6*BF**0.68*PTOTAL**0.78
      GO TO 2350
C     PRECAST CONCRETE LINER
 2200 IF(ITYPE.EQ.2) GO TO 2235
C     TUNNEL SEGMENT
      IF(ISHAPE-2) 2210,2220,2230
 2210 TPLATE=1.55E-8*(0.1+0.046*BF)*PTOTAL**1.6*EXP(SQRT((6.6-0.56*ALOG
     1(PTOTAL))**2+0.016))
      GO TO 2350
 2220 TPLATE=2.6E-7*(0.1+0.044*BF)*PTOTAL**1.38*EXP(SQRT((9.25-0.775*
     1ALOG(PTOTAL))**2+0.048))
      GO TO 2350
 2230 TPLATE=6.5E-8*(0.1+0.044*BF)*PTOTAL**1.48*EXP(SQRT((11.3-0.94*
     1ALOG(PTOTAL))**2+0.21))
      GO TO 2350
C     SHAFT SEGMENT
 2235 IF(ISHAPS.EQ.1) GO TO 2210
      TPLATE=6.8E-7*(5.+4.7*BF)*PTOTAL**0.93*EXP(SQRT((5.22-0.45*ALOG
     1(PTOTAL))**2+0.08))
      GO TO 2350
C     STEEL SEGMENTED SUPPORT
 2300 IF(ITYPE.EQ.2) GO TO 2335
C     TUNNEL SEGMENT
      IF(ISHAPE-2) 2310,2320,2330
 2310 TPLATE=6.95E-7*BF**0.8*PTOTAL**0.88
      GO TO 2350
 2320 TPLATE=6.6E-4*BF**0.74*PTOTAL**0.39
      GO TO 2350
 2330 TPLATE=8.5E-4*BF**0.71*PTOTAL**0.38
      GO TO 2350
C     SHAFT SEGMENT
 2335 IF(ISHAPS.EQ.1) GO TO 2310
      TPLATE=0.001*BF**0.75*PTOTAL**0.38
 2350 IF(TPLATE.LT.TPLMIN) TPLATE=TPLMIN
C     INPUT   LINER THICKNESS GREATER THAN COMPUTED VALUE WILL BE USED
      IF(TPLATE.LT.TLIN) TPLATE=TLIN
      IF(TLIN.GE.TPLMIN .AND. TLIN.LT.TPLATE) MSTAKE=3
 2354 TSEG=FF*TPLATE
```

(Continued)

```
      IF(TSEG.LT.TSEGMN) TSEG=TSEGMN
      BE=BF+2.*TSEG
      IF(ITYPE.EQ.2) GO TO 2360
C     TUNNEL SEGMENT
      A(I,39)=BE
      A(I,62)=TPLATE
      A(I,11)=TSEG
      A(I,63)=PSOIL
      A(I,64)=PWATER
      A(I,65)=PTOTAL
      GO TO 2600
C     SHAFT SEGMENT
 2360 B(I,29)=BE
      B(I,41)=TPLATE
      B(I,11)=TSEG
      B(I,30)=PSOIL
      B(I,43)=PWATER
      B(I,31)=PTOTAL
      GO TO 2600
C     STEEL RIB WITH LINING
C     LINING THICKNESS
C     FOR CUT-AND-COVER SHAFT CONCRETE LINING IS TO RESIST PSOIL+PWATER.
C     WHEN INPUT LINING GREATER THAN 8 IN., THICKNESS IS CHECKED FOR
C     WATER PRESSURE ONLY
 2400 IF(ICUTNC.EQ.1 .AND. TLIN.LT.0.666) PWATER=PSOIL+PWATER
      IF(ITYPE.EQ.2) GO TO 2435
C     TUNNEL SEGMENT
      IF(ISHAPE-2) 2410,2420,2430
 2410 TL=0.5*BF*PWATER/(288000.-PWATER)
      GO TO 2445
 2420 TL=0.77E-10*BF**0.86*PWATER**1.9*EXP(SQRT((16.9-1.42*ALOG(PWATER))
     1**2+0.32))
      GO TO 2445
 2430 TL=3.8E-7*(7.+4.6*BF)*PWATER**1.035*EXP(SQRT((6.5-0.565*ALOG
     1(PWATER))**2+0.17))
      GO TO 2445
C     SHAFT SEGMENT
 2435 IF(ISHAPS.EQ.1) GO TO 2410
      TL=3.6E-5*(7.+4.6*BF)*PWATER**0.68*EXP(SQRT((2.-0.185*ALOG(PWATER)
     1)**2+0.04))
 2445 IF(TL.LT.TLMIN) TL=TLMIN
C     INPUT   LINING THICKNESS GREATER THAN COMPUTED VALUE WILL BE USED
      IF(TL.LT.TLIN) TL=TLIN
      IF(TLIN.GE.TLMIN .AND. TLIN.LT.TL) MSTAKE=3
      IF(ICUTNC.EQ.0) GO TO 2500
      WEB=0
      GO TO 2545
 2500 B1=BF+2.*TL
C     STEEL RIB SIZE
      IF(ITYPE.EQ.2) GO TO 2535
      IF(ISHAPE-2) 2510,2520,2530
C     TUNNEL SEGMENT
 2510 WEB=0.0115*B1**0.39*PSOIL**0.33
      GO TO 2540
 2520 WEB=0.066*B1**0.76*(PSOIL/1000.)**(0.6*B1**(-0.3))
      GO TO 2540
 2530 WEB=0.067*B1**0.78*(PSOIL/1000.)**(0.565*B1**(-0.29))
      GO TO 2540
```

(Continued)

```
C       SHAFT SEGMENT
 2530   IF(ISHAPE.EQ.1) GO TO 2510
        WEB=0.1*B1**0.7*(PSOIL/1000.)**(0.305-0.0027*B1)
 2540   IF(WEB.LT.0.5) WEB=0.5
 2545   BE=BF+2.*TL+2.*WEB
        IF(ITYPE.EQ.2) GO TO 2550
        A(I,39)=BE
        A(I,62)=WEB
        A(I,11)=TL
        A(I,63)=PSOIL
        A(I,64)=PWATER
        A(I,65)=PTOTAL
        GO TO 2600
 2550   B(I,29)=BE
        B(I,41)=WEB
        B(I,11)=TL
        B(I,30)=PSOIL
        B(I,43)=PWATER
        B(I,31)=PTOTAL
C       CHECK IF INPUT THICKNESS ACCEPTED WHEN WATER PRESSURE=0
 2600   IF(I2.EQ.1) GO TO 4000
C       CHECK IF ASSUMED  'BE'  IS WITHIN ONE PERCENT OF COMPUTED  'BE'
        IF(BE/BBEE.LT.0.99 .OR. BE/BBEE.GT.1.01) GO TO 1009
        IF(ITYPE.EQ.2) GO TO 2605
        IF(MSTAKE.EQ.1) WRITE(LO,1010) NTSEG,NREACH
        IF(MSTAKE.EQ.3) WRITE(LO,2710) NTSEG,NREACH
        GO TO 4000
 2605   IF(MSTAKE.EQ.1) WRITE(LO,1011) NSSEG,NSHAFT
        IF(MSTAKE.EQ.3) WRITE(LO,2711) NSSEG,NSHAFT
        GO TO 4000
C
C
C
C
C       *****************************************************************
C       CUT AND COVER ONLY
C       *****************************************************************
C
C       -----------------------------------------------------------------
C       DATA
C       -----------------------------------------------------------------
 2900   IF(ITYPE.EQ.2) GO TO 3300
        ELROCK=A(I,27)
        ELIMP=A(I,24)
        D10=A(I,19)
        PERM=A(I,25)
        DROCK=ELSURF-ELROCK
        NBOX=TRDATA(NREACH,10)
        BFBWDT=TRDATA(NREACH,11)
        BFBHT=TRDATA(NREACH,12)
        IBOX2=TRDATA(NREACH,13)
        IDECK=A(I,29)
        IBRACE=A(I,28)
        DTUN=ELSURF-ELAVG
        IF(IBOX2.EQ.1) GO TO 3000
        BOXWDT=BFBWDT/NBOX
        BOXHT=BFBHT
        GO TO 3001
```

(Continued)

```
 3000 BOXWDT=BFBWDT/2.
      BOXHT=BFBHT/2.
      NBOX=2
 3001 SURGE=400.
      TROOF=0.0
      TINVT=0.0
      TINSB=0.0
      TINWL=0.0
      TEXWL=0.0
      WTROOF=0.0
      WTINSB=0.0
      K=0
C     -------------------------------------------------------------
 3002 DTRNCH=DTUN+BFBHT/2+TINVT+TINSB/2.
      DSOIL=DTRNCH
      IF(DROCK.LT.DTRNCH) DSOIL=DROCK
      TOTBOX=BFBHT+TINVT+TROOF+TINSB
      DROOF=DTRNCH-TOTBOX
      WATPRI=0
      WATPRR=0
      IF(DWATER.GE.DTRNCH) GO TO 3005
      WATPRI=62.4*(DTRNCH-DWATER)
      IF(DWATER.LT.DROOF) WATPRR=WATPRI-62.4*TOTBOX
C     -------------------------------------------------------------
C     TRENCH PRESSURE FOR SUPPORTS
C     -------------------------------------------------------------
 3005 SIGMAT=GAMMA*DSOIL
      SIGMA1=GAMMA*DSOIL
      IWATER=A(I,23)
      STABNO=A(I,30)
      IF(DWATER.LT.DSOIL.AND.IWATER.EQ.0) SIGMA1=GAMMA*DWATER+(GAMMA-
     162.4)*(DSOIL-DWATER)
      IF(STABNO.LT.0.01) STABNO=(SIGMAT+SURGE)/(COHESN+(SIGMA1+SURGE)/2.
     1*(1-SIN(PHI*PI/180.))*TAN(PHI*PI/180.))
      IF(ISUPPT.EQ.5.OR.MEX.EQ.7) GO TO 3010
C     SLURRY WALL TRENCH SUPPORT
      TRENPR=0.3*SIGMAT
      IF(IWATER.EQ.1.AND.D10.GT.0.005) GO TO 3025
      IF(DWATER.LT.DSOIL) TRENPR=0.3 *(GAMMA*DWATER**2.+(GAMMA-62.4)*
     1(DSOIL-DWATER)**2.+2.*GAMMA*DWATER*(DSOIL-DWATER)+2.*62.4*(DSOIL-
     2DWATER)**2.)/DSOIL
      GO TO 3025
C     SOLDIER PILE / LAGGING TRENCH SUPPORT
 3010 TEMP1=0.6*GAMMA*DSOIL*(TAN(PI/180.*(45.-PHI/2.)))**2.
      TEMP2=2.4*COHESN*TAN(PI/180.*(45.-PHI/2.))
      IF(STABNO.LE.4) GO TO 3015
      TM=1.1-0.1*STABNO
      IF(TM.LT.0.4) TM=0.4
      TRENPR=TEMP1*(PHI+0.83)/(PHI+0.62)-TEMP2*(PHI+0.83)/(PHI+0.62)*TM
      GO TO 3020
 3015 TRENPR=TEMP1*(PHI+0.14)/(PHI+0.35)-TEMP2*PHI/(PHI+0.2)
 3020 IF(TRENPR.LT.0.0) TRENPR=0.0
C     -------------------------------------------------------------
C     EARTH PRESSURE FOR BOX MEMBERS
 3025 ERTHPR=0.5*GAMMA*DTUN
C     -------------------------------------------------------------
C     THICKNESS OF BOX MEMBERS
C     -------------------------------------------------------------
```

(Continued)

```
      ULTCOM=5.0*10.**3.
      ALLCOM=0.45*ULTCOM
      AXIALW=0.0
      AXIALS=0.0
      PSOIL=ERTHPR+SURGE
      J=0
C     SOIL AND WATER LOADS ON BOX MEMBERS
C     INPUT THICKNESS WILL NOT BE USED
      IF(TLIN.GT.0.0) WRITE(LO,3500) NTSEG,NREACH
C     ---------------------------------------------------------------
C     AXIAL LOAD AND UNIFORM LOADS
 3030 J=J+1
      GO TO (3040,3050,3060,3070,3080),J
C     ROOF SLAB
 3040 PTOTAL=GAMMA*DROOF/1.1+WTROOF+SURGE
      GO TO 3052
 3050 TROOF=THICK/12.
      WTROOF=150.*TROOF
C     INVERT SLAB
      PWATER=WATPRI-WATPRR
      PTOTAL=PTOTAL+PWATER
 3052 IF(WATPRI.EQ.0.0) GO TO 3055
      IF(WATPRR.GT.0.0) AXIALW=0.25*BOXHT*(WATPRI+WATPRR)
      IF(WATPRR.EQ.0.0) AXIALW=0.25*BOXHT*WATPRI*(DTRNCH-DWATER)/TOTBOX
 3055 IF(DROCK.GE.DTRNCH) GO TO 3057
      IF(DROCK.LE.DROOF) GO TO 3058
      PSOIL=PSOIL*(DROCK-DROOF)/TOTBOX
 3057 AXIALS=0.5*PSOIL*BOXHT
 3058 AXIAL=AXIALW+AXIALS
      SPANL=BOXWDT
      GO TO 3100
 3060 TINVT=THICK/12.
C     INTERIOR SLAB
      IF(IBOX2.EQ.1) GO TO 3062
      THICK=0.0
      GO TO 3030
 3062 PTOTAL=400.+WTINSB
      IF(WATPRI.EQ.0.0) GO TO 3065
      AXIALW=2.0*AXIALW
 3065 IF(DROCK.LE.DROOF) GO TO 3067
      AXIALS=2.0*AXIALS
 3067 AXIAL=AXIALS+AXIALW
      SPANL=BOXWDT
      GO TO 3100
 3070 TINSB=THICK/12.
      WTINSB=150.*TINSB
      K=K+1
      IF(K.EQ.1) GO TO 3002
C     INTERIOR WALL
      AXIAL=(GAMMA*DROOF/1.1+SURGE+WTROOF+WTINSB+400.)*BOXWDT
      SPANL=BOXHT
      IF(NBOX.GT.1) GO TO 3105
      THICK=0.0
      GO TO 3030
 3080 TINWL=THICK/12.
C     EXTERIOR WALL
      AXIAL=AXIAL/2.
      SPANL=BOXHT
```

(Continued)

```
      IF(DWATER.GE.DTRNCH.AND.ISUPPT.EQ.6.)GO TO 3105
      IF(ISUPPT.EQ.6.OR.DROCK.LE.DRCOF) PSOIL=0.0
      PWATER=0.0
      IF(WATPRI.EQ.0.0) GO TO 3085
      IF(WATPRR.GT.0.0) PWATER=(WATPRI+WATPRR)/2.
      IF(WATPRR.EQ.0.0) PWATER=0.5*WATPRI*(DTRNCH-DWATER)/TOTBOX
 3085 PTOTAL=PSOIL+PWATER
C     ---------------------------------------------------------------
C     THICKNESS COMPUTATION
 3100 MOMENT=0.1*PTOTAL*SPANL**2.
      THICK=AXIAL/(24.*ALLCOM)+SQRT((AXIAL/(12.*ALLCOM))**2.+24.*MOMENT/
     1ALLCOM)/2.
      GO TO 3110
 3105 THICK=AXIAL/18800.
C     COSTUN MINIMUM
 3110 IF(THICK.LT.8.0) THICK=8.0
C     ACI REQUIREMENT
      IF(THICK.LT.SPANL*12./25.) THICK=12.*SPANL/25.
      IF(J.LT.5) GO TO 3030
      TEXWL=THICK/12.
C     ---------------------------------------------------------------
C     FINAL OVERALL BOX DIMENSIONS
      TOTBOX=BFBHT+TROOF+TINVT+TINSB
      WDTBOX=BFBWDT+2.*TEXWL+(NBOX-1)*TINWL
      BE=WDTBOX
C     FINAL TRENCH DEPTH
      DTRNCH=DTUN+BFBHT/2.+TINVT+TINSB/2.
      DSOIL=DTRNCH
      IF(DROCK.LT.DTRNCH) DSOIL=DROCK
      DROOF=DTRNCH-TOTBOX
      CONSTR=6.0
      IF(DROCK.GT.DROOF.AND.ISUPPT.NE.6) BE=BE+CONSTR
C     INITIALIZE
      WTWALE=0.
      WTSTRT=0.
      WTANCH=0.
      WTSP=0.
      WTSPD=0.
      SPDLT=0.
      DSP=0.
      DSPD=0.
      SIDESL=0.
      DSLURY=0.0
      IF(MEX.EQ.7) GO TO 3140
      IF(DROCK.LT.0.1) GO TO 3190
      IF(ISUPPT.EQ.5) GO TO 3120
C     ---------------------------------------------------------------
C     SLURRY WALL SUPPORT SYSTEM
C     ---------------------------------------------------------------
C     COMPUTE LENGTH OF SLURRY WALL
C     IS ROCK LINE ABOVE TRENCH BOTTOM
      IF(DROCK.LT.DTRNCH) GO TO 3117
C     IS ROCK LINE SHALLOWER THAN 8 FT BELOW TRENCH
      IF(DROCK.LT.DTRNCH+8.) GO TO 3116
C     IS GROUNDWATER TABLE BELOW TRENCH BOTTOM
      IF(DWATER.GT.DTRNCH) GO TO 3115
      IF(IWATER.EQ.1 .AND.  D10.GT.0.005) GO TO 3115
      IF(D10.GT.0.005) GO TO 3112
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(Continued)

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C     WEIGHTED CREEP RATIO DETERMINES SLURRY WALL PENETRATION
      CREPMN=(340.+1.55*COHESN)/COHESN
      GO TO 3113
 3112 CREPMN=4.3-1.8*ALOG10(SQRT(10.*ABS(PERM)))
 3113 DSLURY=DTRNCH+10.
      CREEP=(2.*DSLURY-DWATER-DTRNCH)/(DTRNCH-DWATER)
      IF(CREEP.GT.CREPMN) GO TO 3120
      DSLURY=(CREPMN*(DTRNCH-DWATER)+DWATER+DTRNCH)/2.
      DTIMP=ELSURF-ELIMP
      IF(DTIMP.GE.DSLURY.OR.D10.LE.0.005) GO TO 3114
C     SLURRY WALL PENETRATES IMPERVIOUS LAYER
      H1=DTIMP-DWATER
      IF(H1.LT.0.) H1=0.
      H2=DTIMP-DTRNCH
      H2DN=H2
      H2UP=DTRNCH-DTIMP
      IF(DTIMP.GE.DTRNCH) H2UP=0.
      IF(DTIMP.LT.DTRNCH) H2DN=0.
      AA=4.
      BB=4.*ABS(H2)+4*H2
      CC=H1**2.+H2**2.+2.*H1*ABS(H2)+2.*H2UP*(H2-H1)+CREPMN*(H2-H1)*
     1(H2DN+H1)
      PENIMP=(-BB+SQRT(BB**2.-4.*AA*CC))/2./AA
      IF(DTIMP.GE.DTRNCH) DSLURY=DTIMP+PENIMP
      IF(DTIMP.LT.DTRNCH) DSLURY=DTRNCH+PENIMP
C     MINIMUM EMBEDMENT FOR ALL SLURRY WALLS IN SOIL
      IF(DSLURY.LT.DTRNCH+10.) DSLURY=DTRNCH+10.
 3114 IF(DSLURY.GT.DROCK+2.) DSLURY=DROCK+2.
      GO TO 3120
C     MINIMUM EMBEDMENT FOR ALL SLURRY WALLS IN SOIL
 3115 DSLURY=DTRNCH+10.
      GO TO 3120
C     MINIMUM EMBEDMENT FOR ALL SLURRY WALLS IN ROCK
 3116 DSLURY=DROCK+2.
      GO TO 3120
C     IS ROCK LINE AT LEAST 2 FT ABOVE ROOF OF BOX
 3117 IF(DROCK+2. .LT.DROOF) GO TO 3118
      DSLURY=DTRNCH+2.
      GO TO 3120
 3118 DSLURY=DROCK+2.
C     ----------------------------------------------------------------
C     SOLDIER PILE/LAGGING SUPPORT SYSTEM
C     ----------------------------------------------------------------
 3120 TRENPR=TRENPR+SURGE
C     ANCHORS AND/OR STRUTS
      WTSTRT=0.0225*TRENPR+0.8*BE
      ANCHDI=0.94*SQRT(TRENPR/1000.)
      IF(ANCHDI.LT.0.5) ANCHDI=0.5
      WTANCH=PI*(ANCHDI/2.)**2.*0.283*12.
      IF(IBRACE.EQ.1) WTANCH=0.
      IF(IBRACE.EQ.2) WTSTRT=0.
      IF(ISUPPT.EQ.6) GO TO 3190
C     WALES
      WTWALE=SQRT(5.6*TRENPR)
      IF(WTWALE.LT.13.) WTWALE=13.
      DWALE=SQRT(6.*WTWALE)-5.0
C     SOLDIER PILES
C     NON DECKED SOLDIER PILES
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(Continued)

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      UTSP =SQRT(TRENPR)
      IF(UTSP.LT.13.) UTSP=13.
      DSP=SQRT(6.*UTSP)-5.0
      IF(IDECK.EQ.0) GO TO 3125
C     DECKED SOLDIER PILES
      SPAXAL=15.*BE/2.*400.
      UTSPD=SQRT(TRENPR)+0.222*SPAXAL/1000.*(1.0-0.25*(TRENPR/1000.)
     1**0.333)
      IF(UTSPD.LT.13.) UTSPD=13.
      DSPD=SQRT(6.*UTSPD)-5.0
C     IS ROCK LINE ABOVE TRENCH BOTTOM
      IF(DROCK.LE.DTRNCH) GO TO 3124
      DPILEH=1./6.*SQRT(1.5*UTSPD)
      IF(PHI.GT.0.) GO TO 3122
      SPDLT=DTRNCH+(1.75*SPAXAL/(0.5*PI*DPILEH)-6.7*COHESN*DPILEH/2.)/
     1(2.*COHESN+DPILEH/2.*GAMMA)
      GO TO 3123
 3122 CNQ=EXP(PI*TAN(PHI*PI/180.))*(TAN(PI/4.+PHI*PI/360.))**2
      CNC=(CNQ-1.)/TAN(PHI*PI/180.)
      IF(PHI.GT.0.) CNGAM=0.
      IF(PHI.GT.10.) CNGAM=0.3*(PHI-10.)
      IF(PHI.GT.20.) CNGAM=(PHI**2-335.)/22.3
      IF(PHI.GT.35.) CNGAM=8.*(PHI-35.)+40.
      IF(PHI.GT.40.) CNGAM=32.*(PHI-40.)+80.
      AA=GAMMA*TAN(PHI*PI/180.)
      BB=2.*COHESN+DPILEH/2.*GAMMA*CNQ
      CC=1.3*COHESN*DPILEH/2.*CNC+0.6*GAMMA*(0.5*DPILEH)**2*CNGAM
     1-1.75*SPAXAL/(0.5*PI*DPILEH)
      SPDLT=DTRNCH+(-BB+SQRT(BB**2-4.*AA*CC))/(2.*AA)
 3123 IF(SPDLT.LT.DTRNCH+10.) SPDLT=DTRNCH+10.
      IF(SPDLT.GT.DROCK+2.) SPDLT=DROCK+2.
      GO TO 3125
 3124 SPDLT=DTRNCH+2.
C     ---------------------------------------------------------------
C     FOR ROCK DESIGN, CHECK IF EXTERIOR BOX WALL IS SMALLER THAN DEPTH
C     OF SOLDIER PILE EMBEDDED IN WALL
 3125 IF(DROCK.GT.DROOF) GO TO 3130
      IF(DROCK+10..GT.DROOF.AND.TEXWL.LT.DSP/12.) TEXWL=DSP/12.
      IF(TEXWL.LT.DSPD/12.) TEXWL=DSPD/12.
C     ---------------------------------------------------------------
C     IN ROCK, EXCAVATED TRENCH WIDTH EQUALS BOX WIDTH
      WDTBOX=BFBWDT+2*TEXWL+(NBOX-1)*TINWL
      BE=WDTBOX
      GO TO 3190
C     ---------------------------------------------------------------
C     COMPUTE FINAL EXCAVATED TRENCH WIDTH FOR BOX IN SOIL
 3130 IF(IDECK.EQ.0)BE=BE+(2.*DWALE+2.*DSP)/12.
      IF(IDECK.EQ.1)  BE=BE+(2.*DWALE+2.*DSPD)/12.
      GO TO 3190
C     ---------------------------------------------------------------
C     SIDE SLOPE FOR OPEN CUTS IN SOIL
C     ---------------------------------------------------------------
C     ALL SLOPING CUTS EXCEPT CLAYS (D10.LE.0.005) WILL BE DEWATERED
 3140 IF(COHESN.GT.0.0) GO TO 3150
C     MATERIALS CHARACTERIZED BY PHI ONLY
      SIDESL=1.25/TAN(PHI*PI/180.)
      GO TO 3190
C     MATERIALS CHARACTERIZED BY COHESION ONLY OR BY PHI AND COHESION
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(Continued)

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 3150 SIGGAH=GAMMA*DSOIL
      IF(DWATER.LT.DSOIL.AND.D10.LE.0.005) SIGGAH=GAMMA*DWATER+(GAMMA-
     162.4)*(DSOIL-DWATER)
      PHIDEV=ATAN(TAN(PHI*PI/180.)/1.25)
      SIDESL=0.577
      TEMP1=(1.0-COS(ATAN(1./SIDESL)-PHIDEV))/(4.*SIN(ATAN(1./SIDESL))
     1*COS(PHIDEV))
      TEMP2=COHESN/(1.25*SIGGAH)
      IF(TEMP1.LE.TEMP2) GO TO 3190
C     ------------------------------------------------------------------
C     SLOPE ANGLE IS BETWEEN PHIDEV AND 60 DEGREES
      IF(PHI.EQ.0.0) MAX=11.0
      IF(PHI.GT.0.0) MAX=1/TAN(PHIDEV)
      MIN=0.577
C     ITERATION REQUIRED TO DETERMINE DESIGN SLOPE
 3160 SIDESL=(MIN+MAX)/2.
      TEMP1=(1.0-COS(ATAN(1./SIDESL)-PHIDEV))/(4.*SIN(ATAN(1./SIDESL))*
     1COS(PHIDEV))
      IF(TEMP1.GT.TEMP2) GO TO 3170
      MIN=SIDESL
      IF(MAX-MIN.LE.0.01) GO TO 3180
      GO TO 3160
 3170 MAX=SIDESL
      IF(MAX-MIN.LE.0.01) GO TO 3180
      GO TO 3160
 3180 SIDESL=(MIN+MAX)/2.
C     ------------------------------------------------------------------
C     SUMMARY CUT AND COVER
C     ------------------------------------------------------------------
C     VOLUME DISPLACED BY BOX
 3190 VBOX=TOTBOX*WDTBOX/27.
C     ------------------------------------------------------------------
C     TOTAL VOLUME OF CONCRETE PER FOOT OF BOX
      VL=(WDTBOX*(TROOF+TINVT+TINSB)+BFBHT*(2*TEXWL+(NBOX-1)*TINWL))/27.
C     ------------------------------------------------------------------
C     FORMWORK FOR CAST IN PLACE CONCRETE
      FORMAR=0.
      IF(LINING.NE.1) GO TO 3200
      FORMAR=BFBHT*(2+(NBOX-1)*2)+BFBWDT
      IF(ISUPPT.EQ.5.AND.DROCK.GT.DROOF) FORMAR=FORMAR+2.*TOTBOX
      IF(IBOX2.EQ.1) FORMAR=FORMAR+BFBWDT
C     ------------------------------------------------------------------
C     STORE TRANSFERED VALUES IN 'A' ARRAY
C     ------------------------------------------------------------------
 3200 A(I,30)=STABNO
      IF(ISUPPT.EQ.5) A(I,38)=SPDLT
      IF(ISUPPT.EQ.6) A(I,38)=DSLURY
      A(I,39)=BE
      BOB=BE
      A(I,42)=BOB
      A(I,43)=TOTBOX
      A(I,52)=DTRNCH
      A(I,53)=SIDESL
      A(I,54)=VBOX
      A(I,55)=VL
      A(I,56)=FORMAR
      A(I,63)=WTWALE
      A(I,64)=WTSTRT
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      A(I,65)=UTANCH
      A(I,66)=UTSP
      A(I,67)=UTSPD
      GO TO 4000
C     ----------------------------------------------------------------
C     CUT AND COVER SHAFTS
C     ----------------------------------------------------------------
 3300 ICUTNC=1
      ISUPPT=4
      LINING=1
C     REDUCE UNIT WEIGHT OF SOIL DUE TO BULKING DURING BACKFILLING
      GAMMA=GAMMA/1.1
      GO TO 1000
 4000 CONTINUE
      IF(NSSTYP.EQ.3.OR.NTSTYP.EQ.3) RETURN
C     CHECK IF FACE INFLOW INPUT WHEN GROUND WATER TABLE BELOW SEGMENT
      GI=A(I,9)
      ELAVG=(ELNPL+ELNPR)/2.
      BE=A(I,39)
      ELBOTM=ELAVG-BE/2.
      IF(ISHAPE.EQ.3) ELBOTM=ELAVG-BE/4.
      IF(ITYPE.EQ.1.AND.GI.GT.0.0.AND.ELBOTM.GE.ELWATR) WRITE(LO,3600)
     1NTSEG,NREACH
C     ----------------------------------------------------------------
C     CHECK IF SHAFT SEGMENT IS WET WHEN WATER TABLE IS BELOW SEGMENT
      GI=B(I,9)
      IF(ITYPE.EQ.2.AND.GI.GT.0.0.AND.ELNPB.GT.ELWATR) WRITE(LO,3605)
     1NSSEG,NSHAFT
      RETURN
C
 5000 PWATER=62.4*(ELWATR-ELAVG)
      IF(PWATER.LE.0.001)PWATER=.001
      TL=TLIN
      BF=BF+2*TL+.333
      BE40=BE
      BE60=BE
      BOB=BE
      BOB40=BOB
      BOB60=BOB
      A(I,39)=BE
      A(I,40)=BE40
      A(I,41)=BE60
      A(I,42)=BOB
      A(I,43)=BOB40
      A(I,44)=BOB60
      A(I,64)=PWATER
      A(I,11)=TL
C     ****************************************************************
 1010 FORMAT(/,' **** WARNING **** ---THICKNESS INPUTED FOR SEGMENT',
     1 I4,' IN REACH',I4,' IS LESS THAN IN STANDARD DESIGN.  INPUT   IGN
     2ORED')
 1011 FORMAT(/,' **** WARNING **** ---THICKNESS INPUTED FOR SEGMENT',
     1 I4,' IN SHAFT',I4,' IS LESS THAN IN STANDARD DESIGN.  INPUT IGN
     2ORED')
 2710 FORMAT(/,' **** WARNING **** ---THICKNESS INPUTED FOR SEGMENT ',I4
     1,' IN REACH',I4,' APPEARS TO BE INADEQUATE FOR WATER PRESSURE.'
     2/,'                          COMPUTED THICK. FOR WATER PRESSURE USED')
 2711 FORMAT(/,' **** WARNING **** ---THICKNESS INPUTED FOR SEGMENT ',I4
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     1,' IN SHAFT',I4,' APPEARS TO BE INADEQUATE FOR WATER PRESSURE.
     2/,'                         COMPUTED THICK. FOR WATER PRESSURE USED')
 3500 FORMAT(/1X,'**** REMINDER ****    A LINING THICKNESS WAS INPUT FOR
     1 A CUT AND COVER BOX IN SEGMENT',I4,' IN REACH',I4,'.  INPUT IGNOR
     2ED')
 3600 FORMAT(/,' **** WARNING ****    A GROUND WATER INFLOW WAS SPECIFIE
     1D IN SEGMENT',I5,' IN REACH',I5,' WHEN WATER TABLE IS BELOW BASE O
     2F TUNNEL.'/' INFLOW IGNORED IN COST COMPUTATIONS.')
 3605 FORMAT(/,' **** WARNING ****    WET GROUND SPECIFIED IN SEGMENT',
     1I5,' IN SHAFT',I5,' WHEN WATER TABLE IS BELOW SEGMENT.'/' WET GROU
     2ND IGNORED IN COST COMPUTATIONS.')
C     ****************************************************************
C
C
      RETURN
      END
      SUBROUTINE STABIL(I,A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX
     1,NTRMAX)
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C     THIS SUBROUTINE SELECTS THE STABILITY NUMBER,STABILIZATION METHOD,
C     AND EXCAVATION METHOD   TO BE USED IN SOFT GROUND TUNNEL AND SHAFT
C     SEGMENTS
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON /F/ IERROR,ISTOP
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C     DO NOT COMPUTE A STABILITY NUMBER IF ONE WAS INPUT. ALSO, DO NOT
C     COMPUTE ONE FOR PORTALS, DUMMY SHAFTS, AND CUT-AND-COVER SEGMENTS.
      IF(ITYPE.EQ.1) GO TO 1000
C     ----------------------------------------------------------------
C     THIS IS A SHAFT SEGMENT
C     CHECK FOR ROCK OR CUT AND COVER SEGMENTS AND FOR A PORTAL OR
C     A DUMMY SHAFT
      NSSTYP=B(I,15)
      IF(NSSTYP.EQ.1) GO TO 500
      IF(NSSTYP.EQ.3) RETURN
      NSHAFT=B(I,1)
      NPORT=SHAFT(NSHAFT,23)
      IF(NPORT.EQ.1) RETURN
      ISHAPS=SHAFT(NSHAFT,16)
      IF(ISHAPS.LT.1) RETURN
      BE     =B(I,29)
      STABNO=B(I,24)
      IF(STABNO.GT.0.01) GO TO 1830
      NSSEG =B(I,2)
      MEX    =B(I,7)
      ELWATR=B(I,13)
      D10    =B(I,16)
      COHESN=B(I,17)
      GAMMA =B(I,18)
      PHI    =B(I,19)
      IWATER=B(I,21)
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      PERM  =B(I,23)
      MSTAB =B(I,25)
      MUST  =B(I,26)
      MSTAC =B(I,28)
      SEGDEP=B(I,36)
      NPTS  =SHAFT(NSHAFT,2)
      ELSURF=CNP(NPTS,2)
      ELAVG =ELSURF-SEGDEP
      GO TO 1003
C     ROCK SHAFT
  500 AIRPR=0
      B(I,27)=AIRPR
      MSTAB=0
      B(I,25)=MSTAB
      RETURN
C     ------------------------------------------------------------------
C     THIS IS A TUNNEL SEGMENT
 1000 NTSTYP=A(I,16)
      IF(NTSTYP.EQ.1) GO TO 1002
      IF(NTSTYP.EQ.3) RETURN
      BE    =A(I,39)
      STABNO=A(I,30)
      IF(STABNO.GT.0.01) GO TO 1830
      NTSEG =A(I,1)
      NPL   =A(I,2)
      NPR   =A(I,3)
      NREACH=A(I,4)
      NEX   =A(I,7)
      ELWATR=A(I,14)
      NPLS  =A(I,17)
      NPRS  =A(I,18)
      D10   =A(I,19)
      PHI   =A(I,20)
      COHESN=A(I,21)
      GAMMA =A(I,22)
      IWATER=A(I,23)
      ELIMP=A(I,24)
      PERM  =A(I,25)
      MSTAB =A(I,31)
      MUST  =A(I,32)
      MSTAC =A(I,34)
      ISHAPE=TRDATA(NREACH,3)
      ELNPL =CNP(NPL,2)
      ELNPR =CNP(NPR,2)
      ELNPLS=CNP(NPLS,2)
      ELNPRS=CNP(NPRS,2)
      ELSURF=(ELNPLS+ELNPRS)/2.
      ELAVG =(ELNPL+ELNPR)/2.
      SEGDEP=ELSURF-ELAVG
      GO TO 1003
C     ROCK TUNNEL
 1002 AIRPR=0
      A(I,33)=AIRPR
      MSTAB=0
      A(I,31)=MSTAB
      RETURN
 1003 AIRPR=0.
C     COMPUTE STABILITY NUMBER BASED ON INPUT PARAMETERS
```

(Continued)

```
      MSTABT=0                                                          039620 0000
      CALL STABNU(COHESN,ELAVG,ELSURF,ELWATR,GAMMA,ISHAPE,ISHAPS,ITYPE, 039630 0000
     1 PHI,SHRSTR,SIGMAT,STABNM,BE,MSTABT,GAMMAA,GAMMAB,GAMMAC,F,FSHAPE, 039640 0000
     2 SEGDEP)                                                          039650 0000
      STABNO=STABNM                                                     039660 0000
C     CHECK WHETHER A PREFERRED STABILIZATION METHOD WAS INPUT.  THE    039670 0000
C     PREFERENCE COULD BE FOR USE OF NO METHOD AT ALL.                  039680 0000
      IF(MUST.GE.3) GO TO 1500                                          039690 0000
C     NO METHOD IS PREFERRED BY USER. CHECK IF SEGMENT CAN BE EXCAVATED. 039700-
  040100 0000
C     THE PREFERRED METHOD IS DEWATERING                                040110 0000
 1010 MSTAB=2                                                           040120 0000
      MSTABT=2                                                          040130 0000
      CALL STABNU(COHESN,ELAVG,ELSURF,ELWATR,GAMMA,ISHAPE,ISHAPS,ITYPE, 040140 0000
     1 PHI,SHRSTR,SIGMAT,STABNM,BE,MSTABT,GAMMAA,GAMMAB,GAMMAC,F,FSHAPE, 040150 0000
     2 SEGDEP)                                                          040160 0000
      GO TO 1030                                                        040170 0000
C     THE PREFERRED METHOD IS COMPRESSED AIR                            040180 0000
 1015 CALL AIRPRS(AIRPR,D10,ELAVG,ELWATR,IERROR,ITYPE,PHI,SHRSTR,SIGMAT, 040190 0000
     1STABNM,STABNO,LO,NREACH,NSHAFT,NSSEG,NTSEG)                       040200 0000
      MSTAB=1                                                           040210 0000
 1030 IF(ITYPE.EQ.1) A(I,30)=STABNM                                     040220 0000
      IF(ITYPE.EQ.1) A(I,31)=MSTAB                                      040230 0000
      IF(ITYPE.EQ.1) A(I,33)=AIRPR                                      040240 0000
      IF(ITYPE.EQ.2) B(I,24)=STABNM                                     040250 0000
      IF(ITYPE.EQ.2) B(I,25)=MSTAB                                      040260 0000
      IF(ITYPE.EQ.2) B(I,27)=AIRPR                                      040270 0000
C     CHECK WHETHER THE SEGMENT CAN BE EXCAVATED AFTER STABILIZATION    040280 0000
 1035 IF(STABNM.LE.9. .AND.PHI.LT.29. .OR. STABNM.LE.7. .AND.PHI.GE.29.) 040290 0000
     1 GO TO 1050                                                       040300 0000
C     SEGMENT CANNOT BE EXCAVATED EVEN AFTER USING A STABILIZATION METH. 040310 0000
      IERROR=1                                                          040320 0000
      IF(ITYPE.EQ.1) WRITE(LO,2000)NTSEG,NREACH                         040330 0000
      IF(ITYPE.EQ.2) WRITE(LO,3000)NSSEG,NSHAFT                         040340 0000
      RETURN                                                            040350 0000
C     SEGMENT CAN NOW BE EXCAVATED. STORE THE NEW STABILITY NUMBER      040360 0000
 1050 STABNO=STABNM                                                     040370 0000
      GO TO 1800                                                        040380 0000
C     ------------------------------------------------------------------ 040390 0000
C     SEGMENT CAN BE EXCAVATED WITHOUT BENEFIT OF STABILIZATION         040400 0000
C     IF USER WILL ALLOW A STABILIZATION METHOD AND STABILITY NUMBER IS 040410 0000
C     HIGH,CHECK WHETHER USE OF STABILIZATION WILL DECREASE STABILITY   040420 0000
C     NUMBER BY AT LEAST 1.0                                            040430 0000
C     ------------------------------------------------------------------ 040440 0000
 1200 IF(STABNO.LE.4.) GO TO 1300                                       040450 0000
      IF(MUST.GT.1) GO TO 1300                                          040460 0000
C     USER WILL ALLOW STABILIZATION TO BE USED                          040470 0000
      IF(D10.LE. .005) GO TO 1215                                       040480 0000
      AIRPR=0.                                                          040490 0000
      IF(ELAVG.GE.ELWATR .OR.IWATER.EQ.0) GO TO 1205                    040500 0000
      IF(PERM.LT.0. .AND.ABS(PERM).GT.0.0006) GO TO 1209                040510 0000
      IF(PERM.GT.0. .AND. D10.GT.0.08) GO TO 1209                       040520 0000
C     THE FIRST CHOICE METHOD IS GROUND INJECTIONS                      040530 0000
 1205 MSTAB=3                                                           040540 0000
      COHSGI=20000.*SQRT(10.*ABS(PERM))                                 040550 0000
      STABNM=SIGMAT/(SHRSTR+COHSGI)                                     040560 0000
      IF(STABNO-STABNM.GE.1.) GO TO 1235                                040570 0000
C     DECREASE IN STABILITY NUMBER CAUSED BY USE OF GROUND INJECTIONS IS 040580 0000
```

(Continued)

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C     SMALL. IF COMPRESSED AIR IS ACCEPTABLE,CHECK IF IT GIVES GREATER
C     DECREASE.
      IF(PERM.LT.0. .AND. ABS(PERM).GT.0.4) GO TO 1235
      IF(PERM.GT.0. .AND.D10.GT.2.) GO TO 1235
      IF(ELAVG.GE.ELWATR) GO TO 1207
      IF(ELWATR-ELAVG.GT.115.) GO TO 1235
C     COMPRESSED AIR IS AN ACCEPTABLE METHOD.
 1207 CALL AIRPRS(AIRPR,D10,ELAVG,ELWATR,IERROR,ITYPE,PHI,SHRSTR,SIGMAT,
     1STABNM,STABNO,LO,NREACH,NSHAFT,NSSEG,NTSEG)
      MSTAB=1
      GO TO 1235
 1209 IF(SEGDEP.LE.150.) GO TO 1210
C     GROUND WOULD BE DEWATERED EXCEPT THAT SEGMENT IS DEEPER THAN IS
C     USUALLY DESIRED. TRY GROUND INJECTIONS FIRST. IF STABILITY NUMBER
C     DOES NOT CHANGE BY MUCH,TRY DEWATERING INSTEAD.
      COHSGI=20000.*SQRT(10.*ABS(PERM))
      STABNM=SIGMAT/(SHRSTR+COHSGI)
      IF(STABNO-STABNM.GE.1.) GO TO 1235
C     THE PREFERRED METHOD IS DEWATERING
 1210 MSTAB=2
      MSTABT=2
      CALL STABNU(COHESN,ELAVG,ELSURF,ELWATR,GAMMA,ISHAPE,ISHAPS,ITYPE,
     1 PHI,SHRSTR,SIGMAT,STABNM,BE,MSTABT,GAMMAA,GAMMAB,GAMMAC,F,FSHAPE,
     2 SEGDEP)
      GO TO 1235
C     THE PREFERRED METHOD IS COMPRESSED AIR
 1215 MSTAB=1
      CALL AIRPRS(AIRPR,D10,ELAVG,ELWATR,IERROR,ITYPE,PHI,SHRSTR,SIGMAT,
     1 STABNM,STABNO,LO,NREACH,NSHAFT,NSSEG,NTSEG)
C     CHECK FOR STABILITY NUMBER DECREASE OF AT LEAST 1.0
 1235 IF(STABNO-STABNM.GE.1.) GO TO 1245
C     STABILITY NUMBER DECREASE IS LESS THAN 1.0  FORGET STABILIZATION
C     METHOD AND EXCAVATE USING ORIGINAL GROUND CONDITIONS
      MSTAB=0
      AIRPR=0.
      IF(ITYPE.EQ.1) GO TO 1240
      WRITE(LO,3010) NSSEG,NSHAFT
      B(I,24)=STABNO
      B(I,25)=MSTAB
      B(I,27)=AIRPR
      GO TO 1800
 1240 WRITE(LO,2010) NTSEG,NREACH
      A(I,30)=STABNO
      A(I,31)=MSTAB
      A(I,33)=AIRPR
      GO TO 1800
C     STABILITY NUMBER DECREASED BY AT LEAST 1.0  USE STABILIZATION
C     METHOD AND NEW STABILITY NUMBER
 1245 IF(MSTAB.GT.1) AIRPR=0.
      IF(ITYPE.EQ.1) GO TO 1250
      B(I,24)=STABNM
      B(I,25)=MSTAB
      B(I,27)=AIRPR
      STABNO=STABNM
      GO TO 1800
 1250 A(I,30)=STABNM
      A(I,31)=MSTAB
      A(I,33)=AIRPR
```

(Continued)

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      STABNO=STABNM
      GO TO 1800
 1300 IF(ITYPE.EQ.1) A(I,30)=STABNO
      IF(ITYPE.EQ.2) B(I,24)=STABNO
      GO TO 1800
C     ******************************************************************
C     A PREFERRED STABILIZATION METHOD WAS INPUT.  THE PREFERENCE COULD
C     BE FOR USE OF NO METHOD AT ALL.
C     CAN THE SEGMENT BE EXCAVATED WITHOUT STABILIZATION
 1500 IF(STABNO.LE.9. .AND.PHI.LT.29. .OR.STABNO.LE.7. .AND.PHI.GE.29.)
     1 GO TO 1600
C     ------------------------------------------------------------------
C     CHECK IF USER WILL ALLOW SOME METHOD TO BE USED.
      IF(MSTAB.GT.0) GO TO 1502
      IERROR=1
      IF(ITYPE.EQ.1) WRITE(LO,2050) NTSEG,NREACH
      IF(ITYPE.EQ.2) WRITE(LO,3050) NSSEG,NSHAFT
      GO TO 1530
C     ------------------------------------------------------------------
C     SEGMENT CANNOT BE EXCAVATED WITHOUT STABILIZATION. CHECK WHETHER
C     USERS PREFERRED METHOD IS ACCEPTABLE
 1502 IF(ITYPE.EQ.2) GO TO 1505
      IF(MSTAC.EQ.1) GO TO 1510
C     METHOD IS UNACCEPTABLE
      IERROR=1
      WRITE(LO,3030) NSSEG,NSHAFT
      RETURN
 1505 IF(MSTAC.EQ.1) GO TO 1510
C     METHOD IS UNACCEPTABLE
      IERROR=1
      WRITE(LO,2030) NTSEG,NREACH
      RETURN
C     ------------------------------------------------------------------
C     STABILIZATION METHOD INPUT IS ACCEPTABLE
C     CHECK FOR PREFERRED METHOD
 1510 IF(MSTAB.EQ.1) GO TO 1520
      IF(MSTAB.EQ.3) GO TO 1518
C     THE PREFERRED METHOD IS DEWATERING
      MSTABT=2
      CALL STABNU(COHESN,ELAVG,ELSURF,ELWATR,GAMMA,ISHAPE,ISHAPS,ITYPE,
     1 PHI,SHRSTR,SIGMAT,STABNM,BE,MSTABT,GAMMAA,GAMMAB,GAMMAC,F,FSHAPE,
     2 SEGDEP)
      GO TO 1525
C     THE PREFERRED METHOD IS GROUND INJECTIONS
 1518 COHSGI=20000.*SQRT(10.*ABS(PERM))
      STABNM=SIGMAT/(SHRSTR+COHSGI)
      GO TO 1525
C     THE PREFERRED METHOD IS COMPRESSED AIR
 1520 IF(ITYPE.EQ.1) AIRPR=A(I,33)
      IF(ITYPE.EQ.2) AIRPR=B(I,27)
C     IF AIR PRESSURE IS INPUT,USE IT AND COMPUTE STABILITY NUMBER.IF
C     NONE IS INPUT,COMPUTE AIR PRESSURE
      IF(AIRPR.GT.0.) GO TO 1522
      CALL AIRPRS(AIRPR,D10,ELAVG,ELWATR,IERROR,ITYPE,PHI,SHRSTR,SIGMAT,
     1STABNM,STABNO,LO,NREACH,NSHAFT,NSSEG,NTSEG)
      GO TO 1525
 1522 STABNM=(SIGMAT-AIRPR*144.)/SHRSTR
C     CHECK WHETHER SEGMENT CAN BE EXCAVATED AFTER STABILIZATION
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(Continued)

```
 1525 IF(STABNM.LE.9. .AND.PHI.LT.29. .OR.STABNM.LE.7. .AND.PHI.GE.29.)
     1 GO TO 1530
C      SEGMENT CANNOT BE EXCAVATED EVEN AFTER USING A STABILIZATION METH.
       IERROR=1
       IF(ITYPE.EQ.1) WRITE(LO,2035)NTSEG,NREACH
       IF(ITYPE.EQ.2) WRITE(LO,3035)NSSEG,NSHAFT
       IF(ITYPE.EQ.1) A(I,30)=STABNM
       IF(ITYPE.EQ.1) A(I,33)=AIRPR
       IF(ITYPE.EQ.2) B(I,24)=STABNM
       IF(ITYPE.EQ.2) B(I,27)=AIRPR
       GO TO 1830
C      ----------------------------------------------------------------
C      SEGMENT CAN NOW BE EXCAVATED
 1530  IF(ITYPE.EQ.1) GO TO 1535
       B(I,24)=STABNM
       B(I,27)=AIRPR
       STABNO=STABNM
       GO TO 1800
 1535  A(I,30)=STABNM
       A(I,33)=AIRPR
       STABNO=STABNM
       GO TO 1800
C      ----------------------------------------------------------------
C      SEGMENT CAN BE EXCAVATED WITHOUT BENEFIT OF STABILIZATION METHOD
C      ----------------------------------------------------------------
C      CHECK IF NO METHOD IS TO BE USED
 1600  IF(MSTAB.EQ.0) GO TO 1640
C      CHECK WHETHER USER REQUIRES STABILIZATION METHOD TO BE USED
       IF(MUST.EQ.4) GO TO 1610
C      STABILIZATION IS NOT REQUIRED.FORGET STABILIZATION AND EXCAVATE
C      USING THE ORIGINAL GROUND CONDITIONS.
       IF(ITYPE.EQ.1) GO TO 1605
       WRITE(LO,3015) NSSEG,NSHAFT
       MSTAB=0
       B(I,24)=STABNO
       B(I,25)=MSTAB
       GO TO 1800
 1605  WRITE(LO,2015) NTSEG,NREACH
       MSTAB=0
       A(I,30)=STABNO
       A(I,31)=MSTAB
       GO TO 1800
C      ----------------------------------------------------------------
C      USER REQUIRES USE OF A STABILIZATION METHOD. CHECK IF SPECIFIED
C      METHOD IS ACCEPTABLE. IF METHOD IS UNACCEPTABLE,BASE COSTS ON
C      UNSTABILIZED GROUND
 1610  IF(ITYPE.EQ.1) GO TO 1615
       IF(MSTAC.EQ.1) GO TO 1620
       WRITE(LO,3020) NSSEG,NSHAFT
       GO TO 1800
 1615  IF(MSTAC.EQ.1) GO TO 1620
       WRITE(LO,2020) NTSEG,NREACH
       GO TO 1800
C      ----------------------------------------------------------------
C      STABILIZATION METHOD INPUT IS ACCEPTABLE
C      CHECK FOR PREFERRED METHOD
 1620  IF(MSTAB.EQ.1) GO TO 1630
       IF(MSTAB.EQ.3) GO TO 1625
```

(Continued)

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C      THE PREFERRED METHOD IS DEWATERING
       MSTABT=2
       CALL STABNU(COHESN,ELAVG,ELSURF,ELWATR,GAMMA,ISHAPE,ISHAPS,ITYPE,
      1 PHI,SHRSTR,SIGMAT,STABNM,BE,MSTABT,GAMMAA,GAMMAB,GAMMAC,F,FSHAPE,
      2 SEGDEP)
       GO TO 1635
C      THE PREFERRED METHOD IS GROUND INJECTIONS
 1625  COHSGI=20000.*SQRT(10.*ABS(PERM))
       STABNM=SIGMAT/(SHRSTR+COHSGI)
       GO TO 1635
C      THE PREFERRED METHOD IS COMPRESSED AIR
 1630  IF(ITYPE.EQ.1) AIRPR=A(I,33)
       IF(ITYPE.EQ.2) AIRPR=B(I,27)
C      IF AIR PRESSURE IS INPUT,USE IT AND COMPUTE STABILITY NUMBER.IF
C      NONE IS INPUT,COMPUTE AIR PRESSURE
       IF(AIRPR.GT.0.) GO TO 1632
       CALL AIRPRS(AIRPR,D10,ELAVG,ELWATR,IERROR,ITYPE,PHI,SHRSTR,SIGMAT,
      1STABNM,STABNO,LO,NREACH,NSHAFT,NSSEG,NTSEG)
       GO TO 1635
 1632  STABNM=(SIGMAT-AIRPR*144.)/SHRSTR
C      -----------------------------------------------------------------
C      CHECK FOR STABILITY NUMBER DECREASE OF AT LEAST 1.0
 1635  IF(STABNO-STABNM.GE.1.) GO TO 1640
C      STABILITY NUMBER DID NOT DECREASE BY AT LEAST 1.0 INFORM USER
       IF(ITYPE.EQ.1) WRITE(LO,2025) NTSEG,NREACH
       IF(ITYPE.EQ.2) WRITE(LO,3025) NSSEG,NSHAFT
 1640  IF(ITYPE.EQ.1) A(I,30)=STABNM
       IF(ITYPE.EQ.1) A(I,33)=AIRPR
       IF(ITYPE.EQ.2) B(I,24)=STABNM
       IF(ITYPE.EQ.2) B(I,27)=AIRPR
       STABNO=STABNM
C      *****************************************************************
C      CHECK FOR ACCEPTABLE EXCAVATION METHOD FOR THE STABILITY NUMBER
C      TO BE USED,THE CHECK FOR COMPATIBILITY WITH SHAPE IS IN SUB INPUT
 1800  IF(ITYPE.EQ.1)GO TO 1805
       IF(MEX.EQ.4) GO TO 1830
       IF(MEX.EQ.3 .AND.STABNO.LE.6.) GO TO 1830
C      METHOD IS UNACCEPTABLE,SELECT HAND METHODS INSTEAD
       MEX=4
       B(I,7)=MEX
       WRITE(LO,3040) NSSEG,NSHAFT
       GO TO 1830
 1805  IF(MEX-4) 1820,1830,1810
C      RIPPER EXCAVATION
 1810  IF(STABNO.LE.7.) GO TO 1830
       GO TO 1825
C      MOLE EXCAVATION
 1820  IF(STABNO.LE.6.) GO TO 1830
C      MOLE OR RIPPER ARE UNACCEPTABLE,SELECT HAND INSTEAD
 1825  MEX=4
       A(I,7)=MEX
       WRITE(LO,2040) NTSEG,NREACH
C      *****************************************************************
C      IF STABILITY NUMBER IS LOW,SHIELD IS VERY THIN AND LEAVES LITTLE
C      SPACE FOR BACKFILL BEHIND THE LINING OR SUPPORT
 1830  BOB=BE+1.0
       IF(STABNO.LT.2.) BOB=BE
       IF(ITYPE.EQ.1) A(I,48)=BOB
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(Continued)

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      IF(ITYPE.EQ.2) B(I,32)=B0B
      RETURN
C     ***************************************************************
 2000 FORMAT(/,' FATAL ERROR, STABILITY NUMBER IN SEGMENT',I5, ' IN RE
     1ACH',I5,' IS TOO HIGH TO ALLOW EXCAVATION,EVEN AFTER STABILIZATIO
     2N')
 2010 FORMAT(/,' **** REMINDER ****  USE OF A STABILIZATION METHOD IN
     1SEGMENT',I5,' IN REACH',I5,' IS NOT VERY EFFECTIVE, NO METHOD USE
     2D')
 2015 FORMAT(/,' **** REMINDER ****  USER PREFERRED STABILIZATION METH
     1OD IN SEGMENT',I5,' IN REACH',I5,' IS NOT REQUIRED, METHOD NOT US
     2ED')
 2020 FORMAT(/,' **** WARNING ****  USERS STAB. METHOD IN SEGMENT',I5,
     1 ' IN REACH',I5,' IS NOT ACCEPTABLE NOR REQUIRED, METHOD NOT USE
     2D')
 2025 FORMAT(/,' **** REMINDER **** USE OF STABILIZATION METHOD IN SEG
     1MENT',I5,' IN REACH',I5,' IS NOT VERY EFFECTIVE, METHOD USED ANYW
     2AY')
 2030 FORMAT(/,' FATAL ERROR, USERS STAB. METHOD IN SEGMENT',I5,' IN R
     2EACH',I5,' IS NOT ACCEPTABLE AND STABILITY NUMBER IS TOO HIGH')
 2035 FORMAT(/,' FATAL ERROR, USERS STAB. METHOD IN SEGMENT',I5,' IN R
     1EACH',I5,' IS NOT EFFECTIVE AND STABILITY NUMBER IS TOO HIGH')
 2040 FORMAT(/,' **** REMINDER **** CONDITIONS IN SEGMENT',I5,' IN REA
     1CH',I5,' REQUIRE USE OF HAND EXCAVATION RATHER THAN INPUT METHOD')
 2050 FORMAT(/,' FATAL ERROR, STABILITY NUMBER IN SEGMENT',I5,' IN REA
     1CH',I5,' REQUIRES GROUND STABILIZATION, BUT IT WAS SPECIFIED NO M
     2ETHOD BE USED')
 3000 FORMAT(/,' FATAL ERROR, STABILITY NUMBER IN SEGMENT',I5, ' IN SH
     1AFT',I5,' IS TOO HIGH TO ALLOW EXCAVATION,EVEN AFTER STABILIZATIO
     2N')
 3010 FORMAT(/,' **** REMINDER ****  USE OF A STABILIZATION METHOD IN
     1SEGMENT',I5,' IN SHAFT',I5,' IS NOT VERY EFFECTIVE, NO METHOD USE
     2D')
 3015 FORMAT(/,' **** REMINDER ****  USER PREFERRED STABILIZATION METH
     1OD IN SEGMENT',I5,' IN SHAFT',I5,' IS NOT REQUIRED, METHOD NOT US
     2ED')
 3020 FORMAT(/,' **** WARNING ****  USERS STAB. METHOD IN SEGMENT',I5,
     1 ' IN SHAFT',I5,' IS NOT ACCEPTABLE NOR REQUIRED, METHOD NOT USE
     2D')
 3025 FORMAT(/,' **** REMINDER **** USE OF STABILIZATION METHOD IN SEG
     1MENT',I5,' IN SHAFT',I5,' IS NOT VERY EFFECTIVE, METHOD USED ANYW
     2AY')
 3030 FORMAT(/,' FATAL ERROR, USERS STAB. METHOD IN SEGMENT',I5,' IN S
     1HAFT',I5,' IS NOT ACCEPTABLE AND STABILITY NUMBER IS TOO HIGH')
 3035 FORMAT(/,' FATAL ERROR, USERS STAB. METHOD IN SEGMENT',I5,' IN S
     1HAFT',I5,' IS NOT EFFECTIVE AND STABILITY NUMBER IS TOO HIGH')
 3040 FORMAT(/,' **** REMINDER **** CONDITIONS IN SEGMENT',I5,' IN SHA
     1FT',I5,' REQUIRE USE OF HAND EXCAVATION RATHER THAN INPUT METHOD')
 3050 FORMAT(/,' FATAL ERROR, STABILITY NUMBER IN SEGMENT',I5,' IN SHA
     1FT',I5,' REQUIRES GROUND STABILIZATION, BUT IT WAS SPECIFIED NO M
     2ETHOD BE USED')
C     ---------------------------------------------------------------
C
C
C
      RETURN
```

(Continued)

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      END
      SUBROUTINE STABNU(COHESN,ELAVG,ELSURF,ELWATR,GAMMA,ISHAPE,ISHAPS,
     1 ITYPE,PHI,SHRSTR,SIGMAT,STABNM,BE,MSTABT,GAMMAA,GAMMAB,GAMMAC,F,
     2 FSHAPE,SEGDEP)
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
C     THIS SUBROUTINE COMPUTES THE INITIAL STABILITY NUMBER BASED ONLY
C     ON INPUT GROUND PARAMETERS AND ALSO COMPUTES IT IF STABILIZATION
C     IS BY DEWATERING
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
      PI=3.14159
      SINPHI=SIN(PHI*PI/180.)
      TANPHI=TAN(PHI*PI/180.)
C     CHECK WHETHER THIS IS THE SECOND COMPUTATION FOR THIS SEGMENT.IF
C     SO,CAN BYPASS MOST OF THIS SUBROUTINE.
      IF(MSTABT.EQ.2) GO TO 1150
C     COMPUTE STABILITY NUMBER FOR UNSTABILIZED GROUND
C     CHECK FOR GWT ABOVE GROUND SURFACE
      IF(ELWATR.GT.ELSURF) GO TO 1050
C     CHECK FOR SEGMENT BELOW GWT
      IF(ELAVG.LT.ELWATR) GO TO 1010
C     GWT IS BELOW SEGMENT
      SIGGAH=SEGDEP*GAMMA
      IF(SEGDEP.LE.2.*BE) GO TO 1000
      GAMMAA=GAMMA
      GAMMAB=GAMMA
      GO TO 1100
 1000 GAMMAC=GAMMA
      GO TO 1100
C     SEGMENT IS BELOW GWT
 1010 DWATER=ELSURF-ELWATR
      SIGGAH=DWATER*GAMMA+(ELWATR-ELAVG)*(GAMMA-62.4)
      IF(SEGDEP.LE.2.*BE) GO TO 1030
      IF(DWATER.GT.2.*BE) GO TO 1020
C     SEGMENT IS DEEPER THAN 2BE AND GWT IS WITHIN 2BE OF GROUND SURFACE
      GAMMAA=(GAMMA*DWATER+(GAMMA-62.4)*(2.*BE-DWATER))/(2.*BE)
      GAMMAB=(GAMMA-62.4)
      GO TO 1100
C     SEGMENT AND GWT ARE BOTH DEEPER THAN 2BE
 1020 GAMMAA=GAMMA
      GAMMAB=(GAMMA*(DWATER-2.*BE)+(GAMMA-62.4)*(ELWATR-ELAVG))/(SEGDEP-
     1 2.*BE)
      GO TO 1100
C     SEGMENT IS WITHIN 2BE OF GROUND SURFACE
 1030 GAMMAC=(GAMMA*DWATER+(GAMMA-62.4)*(ELWATR-ELAVG))/SEGDEP
      GO TO 1100
C     GWT IS ABOVE GROUND SURFACE
 1050 GAMMAA=GAMMA-62.4
      GAMMAB=GAMMA-62.4
      GAMMAC=GAMMA-62.4
      SIGGAH=SEGDEP*(GAMMA-62.4)
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C     -----------------------------------------------------------------
 1100 PHIEQR=ATAN(COHESN/SIGGAH+TANPHI)
      PHIEQ=PHIEQR*180./PI
      IF(PHIEQ.GT.45.) PHIEQ=45.
C     ESTABLISH SEGMENT TYPE AND SHAPE FACTORS
      IF(SEGDEP.LE.2.*BE) GO TO 1300
      F=1.0
      FSHAPE=1.0
      IF(ITYPE.EQ.1) GO TO 1110
C     SHAFT SEGMENT
      F=0.5
      FSHAPE=0.5
      IF(ISHAPS.EQ.2) F=0.6
      IF(ISHAPS.EQ.2) FSHAPE=0.6
      GO TO 1200
C     TUNNEL SEGMENT
 1110 IF(ISHAPE.EQ.3) FSHAPE=1.25
      GO TO 1200
C     -----------------------------------------------------------------
C     THE FOLLOWING UNIT WEIGHTS APE FOR STABILIZATION BY DEWATERING
 1150 IF(SEGDEP.LE.2.*BE) GO TO 1160
      GAMMAA=GAMMA
      GAMMAB=GAMMA
      GO TO 1200
 1160 GAMMAC=GAMMA
      GO TO 1350
C     -----------------------------------------------------------------
C     SEGMENT IS DEEPER THAN 2BE
 1200 SIGMAT=2.*BE*GAMMA*F+(SEGDEP-2.*BE)*(0.34-PHIEQ**2./6000.)*
     1 GAMMA*FSHAPE
C     INCREASE SIGMAT IF GWT IS ABOVE GROUND AND SEGMENT NOT DEWATERED
      IF(MSTABT.EQ.2) GO TO 1250
      IF(ELWATR.GT.ELSURF) SIGMAT=SIGMAT+(ELWATR-ELSURF)*62.4
 1250 SIGMA1=2.*BE*GAMMAA*F+(SEGDEP-2.*BE)*(0.34-PHIEQ**2./6000.)*
     1 GAMMAB*FSHAPE
      GO TO 1400
C     SEGMENT IS NO DEEPER THAN 2BE
 1300 F=1.0
      IF(ITYPE.EQ.1) GO TO 1350
C     SHAFT SEGMENT
      F=0.5
      IF(ISHAPS.EQ.2) F=0.6
 1350 SIGMAT=SEGDEP*GAMMA*F
C     INCREASE SIGMAT IF GWT IS ABOVE GROUND AND SEGMENT NOT DEWATERED
      IF(MSTABT.EQ.2) GO TO 1375
      IF(ELWATR.GT.ELSURF) SIGMAT=SIGMAT+(ELWATR-ELSURF)*62.4
 1375 SIGMA1=SEGDEP*GAMMAC*F
C     -----------------------------------------------------------------
```

(Continued)

```
C     COMPUTE STABILITY NUMBER
 1400 FRSTRN=SIGMA1/2.*(1.-SINPHI)*TANPHI
      SHRSTR=COHESN+FRSTRN
      STABNM=SIGMAT/SHRSTR
C     ------------------------------------------------------------------
      RETURN
      END
      SUBROUTINE AIRPRS(AIRPR ,D10,ELAVG,ELWATR,IERROR,ITYPE,PHI,SHRSTR,
     1SIGMAT,STABNM,STABNO,LO,NREACH,NSHAFT,NSSEG,NTSEG)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
C     THIS SUBROUTINE DETERMINES THE AIR PRESSURE TO BE USED FOR SOFT
C     GROUND CONSTRUCTION IN COMPRESSED AIR
C
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CHECK FOR GRANULAR MATERIAL BELOW GWT. IF SO, AIR PRESSURE IS
C     CONTROLLED BY WATER HEAD
      IF(D10.GT. .005 .AND.ELAVG.LT.ELWATR) AIRPR=.433*(ELWATR-ELAVG)
      IF(D10.GT. .005 .AND.ELAVG.LT.ELWATR) RETURN
C     ------------------------------------------------------------------
C     AIR PRESSURE IS NOT CONTROLLED BY WATER HEAD. START BY COMPUTING
C     STABILITY NUMBER USING MINIMUM AIR PRESSURE OF 7 PSI.
      AIRPR=7.0
      STABNM=(SIGMAT-AIRPR*144.)/SHRSTR
C     CHECK FOR STABILITY NUMBER DECREASE OF AT LEAST 1.0
      IF(STABNO-STABNM.GE.1.) GO TO 1100
C     DECREASE LESS THAN 1.0  COMPUTE AIR PRESURE FOR DECREASE= 1.0
      AIRPR=(SIGMAT-(STABNO-1.)*SHRSTR)/144.
C     CHECK FOR AIR PRESSURE GREATER THAN 50 PSI
      IF(AIRPR.GT.50.) GO TO 1000
C     AIR PRESSURE IS LESS THAN 50 PSI.  CAN SEGMENT BE EXCAVATED
      IF(STABNO-1. .LE.9. .AND.PHI.LT.29. .OR.STABNO-1. .LE.7. .AND.PHI
     1 .GE.29.) GO TO 1050
C     SEGMENT CANNOT BE EXCAVATED FOR STABILITY NUMBER DECREASE OF 1.0
C     CAUSED BY APPLICATION OF AIR PRESSURE,OR DECREASE OF 1.0 REQUIRES
C     AIR PRESSURE GREATER THAN 50 PSI. TRY 50 PSI
 1000 AIRPR=50.
      STABNM=(SIGMAT-AIRPR*144.)/SHRSTR
```

(Continued)

```
C     CHECK WHETHER SEGMENT CAN BE EXCAVATED USING 50 PSI
      IF(STABNM.LE.9. .AND. PHI.LT.29. .OR.STABNM.LE.7. .AND.PHI.GE.29.)
     1 GO TO 1200
C     SEGMENT CANNOT BE EXCAVATED USING 50 PSI,MAXIMUM ALLOWABLE PRESS.
      IERROR=1
      IF(ITYPE.EQ.1) WRITE(LO,2000) NTSEG,NREACH
      IF(ITYPE.EQ.2) WRITE(LO,3000) NSSEG,NSHAFT
      GO TO 1200
C     SEGMENT CAN BE EXC USING AIR PRESSURE FOR STABNO DECREASE=1.0
 1050 STABNM=STABNO-1.
      GO TO 1200
C     -----------------------------------------------------------------
C     STABILITY NUMBER DECREASE BY AT LEAST 1.0 FOR 7 PSI AIR PRESSURE.
C     CAN SEGMENT BE EXCAVATED
 1100 IF(STABNM.LE.9. .AND.PHI.LT.29. .OR.STABNM.LE.7. .AND.PHI.GE.29.)
     1 GO TO 1200
C     SEGMENT CANNOT BE EXCAVATED FOR DECREASE=1.0 USING 7 PSI. COMPUTE
C     AIR PRESSURE SO SEGMENT CAN BE EXCAVATED
      SN=9.
      IF(PHI.GE.29.) SN=7.
      AIRPR=(SIGMAT-SN*SHRSTR)/144.
C     CHECK FOR AIR PRESSURE GREATER THAN 50 PSI
      IF(AIRPR.GT.50.) GO TO 1150
C     AIR PRESSURE LESS THAN 50 PSI
      STABNM=SN
      GO TO 1200
C     SEGMENT CANNOT BE EXCAVATED USING 50 PSI,MAXIMUM ALLOWABLE PRESS.
 1150 IERROR=1
      IF(ITYPE.EQ.1) WRITE(LO,2000) NTSEG,NREACH
      IF(ITYPE.EQ.2) WRITE(LO,3000) NSSEG,NSHAFT
 1200 RETURN
C     -----------------------------------------------------------------
 2000 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN REACH',I5,' CANNOT BE
     1EXCAVATED USING LESS THAN 50 PSI AIR PRESSURE FOR STABILIZATION')
 3000 FORMAT(/,' FATAL ERROR, SEGMENT',I5,' IN SHAFT',I5,' CANNOT BE
     1EXCAVATED USING LESS THAN 50 PSI AIR PRESSURE FOR STABILIZATION')
C     -----------------------------------------------------------------
      RETURN
      END
```

(Continued)

```
      SUBROUTINE REACHD(A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     THIS SUBROUTINE DETERMINES THE BEGINNING SEGMENT AND TOTAL
C        NUMBER OF SEGMENTS IN THE REACHES.
C
C     N1 .......... LOCATION IN (A( ARRAY OF LEFT SEGMENT IN A REACH
C     N2 .......... LOCATION IN (A( ARRAY OF RIGHT SEGMENT IN A REACH
C     I ........... TUNNEL SEGMENT SEQUENCE NUMBER
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ------------------------------------------------------------------
      N1=1
      I=0
      IPR=A(1,4)
      NREACH=IPR
      NPL=A(1,2)
      NPR=A(1,3)
      STANPL=CNP(NPL,1)
      STANPR=CNP(NPR,1)
      STAMLS=(STANPL+STANPR)/2.
      NSHAFT=TRDATA(NREACH,1)
      NPBS=SHAFT(NSHAFT,3)
      STANPB=CNP(NPBS,1)
C     ------------------------------------------------------------------
  100 I=I+1
      NREACH=A(I,4)
      IF(I.EQ.NTS+1) GO TO 200
      IF(NREACH.NE.IPR)  GO TO 200
      N2=I
      GO TO 500
C
  200 IF(STAMLS.LT.STANPB) GO TO 250
      NRSEG1=N1
      NSEGS=N2-N1+1
      GO TO 300
  250 NRSEG1=N2
      NSEGS=-(N2-N1+1)
  300 TRDATA(IPR,5)=NRSEG1
      TRDATA(IPR,6)=NSEGS
      IF(I.EQ.NTS+1) GO TO 600
C     ------------------------------------------------------------------
      NPL=A(I,2)
      NPR=A(I,3)
      STANPL=CNP(NPL,1)
      STANPR=CNP(NPR,1)
      STAMLS=(STANPL+STANPR)/2.
      NSHAFT=TRDATA(NREACH,1)
      NPBS=SHAFT(NSHAFT,3)
      STANPB=CNP(NPBS,1)
      IPR=NREACH
```

(Continued)

```
      N1=I
      N2=I
C
  500 IF(I.NE.NTS+1) GO TO 100
  600 CONTINUE
C     ----------------------------------------------------------------
      RETURN
      END
      SUBROUTINE ADRATE (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C
C     THIS SUBROUTINE COMPUTES THE ULTIMATE HEADING ADVANCE RATE FOR
C     SEGMENTS IN WHICH NONE WAS USER SPECIFIED AND COMPUTES THE AVERAGE
C     ADVANCE RATE IN ALL SEGMENTS
C
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C     COMPUTE ADVANCE RATES IN TUNNEL SEGMENTS
      DO 400 NREACH=1,NTRMAX
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 400
      NRSEG1=TRDATA(NREACH,5)
      NSEGS=TRDATA(NREACH,6)
      NSEGSA=IABS(NSEGS)
C     INITIALIZE VALUES
      PINSAR=0.
      MEXP=0
      DO 300 I=1,NSEGSA
C     N=SEQUENCE NUMBER OF TUNNEL SEGMENT
      IF(NSEGS.GT.0) N=NRSEG1+I-1
      IF(NSEGS.LT.0) N=NRSEG1-I+1
      MEX=A(N,7)
      STABNO=A(N,30)
      E=2.71828
      AR=A(N,8)
      TSEGL=A(N,45)
      IF(MEX.GT.5) GO TO 1000
C     CHECK FOR EXCAVATION IN DOWNHILL DIRECTION
C     IF EXCAVATION IS DOWNHILL,ULTIMATE ADVANCE RATE IS ONLY 90 PERCENT
C     OF ULTIMATE RATE FOR LEVEL OR UPHILL EXCAVATION
      SLARF=1.0
      NPL=A(N,2)
      NPR=A(N,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
      SLOPE=(ELNPL-ELNPR)/(CNP(NPL,1)-CNP(NPR,1))
      IF(NSEGS.GT.0 .AND. SLOPE.LT.0. .OR. NSEGS.LT.0 .AND. SLOPE.GT.0.)
     1  SLARF=0.9
      BE=A(N,39)
      RS=A(N,5)
      RQD=A(N,6)
      QI=A(N,9)
```

(Continued)

```
      MSTAB=A(N,31)
      GO TO 30
 1000 ISUPPT=A(N,26)
      GO TO 10
   30 IF(MEX.EQ.MEXP) GO TO 10
C     THIS IS FIRST SEGMENT IN REACH OR EXCAVATION METHOD HAS CHANGED
      BINSAR=0.
      GO TO 20
C     EXCAVATION IS SAME AS IN PREVIOUS SEGMENT
   10 BINSAR=PINSAR-.05
      IF(BINSAR.LT.0.) BINSAR=0.
   20 IF(AR.GT.0.) ARTULT=AR
      IF(AR.GT.0.) GO TO 100
C     ---------------------------------------------
C     AN ULTIMATE ADVANCE RATE HAS NOT BEEN SPECIFIED,MUST COMPUTE ONE
C     COMPUTE SYSTEM ADVANCE RATES IN FEET/24 HOURS
C     CHECK FOR METHOD OF EXCAVATION
 1020 IF(MEX.GT.5) GO TO 1160
C     THIS IS NOT CUT AND COVER
      ISHAPE=TRDATA(NREACH,3)
      IF(MEX.NE.2.AND.MEX.NE.3) GO TO 50
      IF(MEX.EQ.2) GO TO 150
C     ---------------------------------------------
C     MOLE IN SOFT GROUND
      ARTULT=(2.*(STABNO-7.)**2 +1.)/100000.*(80.-BE)**3.*SLARF
      GO TO 1100
C     MOLE IN ROCK
C     ADVANCE RATE EQUATION NOT GOOD FOR ROCK STRENGTH BELOW 3000 PSI
  150 IF(RS.LT.3000.) RS=3000.
      ARTULT=(10000000./(BE*RS))*(.6+.4*SIN(3.14159*(RQD/75.+1.167)))
     1*(GI+1500.)/(5.*GI+1500.)*SLARF
      GO TO 1100
C     ---------------------------------------------
C     CONVENTIONAL EXCAVATION IN ROCK OR HAND OR RIPPER EXC IN SOFT GRND
   50 IF(ISHAPE.EQ.1) SFA=0.785
      IF(ISHAPE.EQ.2) SFA=0.893
      IF(ISHAPE.EQ.3) SFA=0.425
      IF(MEX.EQ.1) ARTULT=((.08*BE**2.25)*RQD+1000.)*((GI+1500.)/
     1 (5.*GI+1500.))/(SFA*BE**1.5*E**(.035*BE)*(1.+.0025*RS/1000.))*
     2 SLARF*(1.-RQD*(BE-10.)/6000.)
      IF(MEX.EQ.1) GO TO 1200
      IF(MEX.EQ.4) ARTULT=(0.3*(STABNO-10.)**2 +1.)/100000.*
     1 (80.-BE)**3.*SLARF*0.785/SFA
      IF(MEX.EQ.5) ARTULT=(1.4*(STABNO-7.5)**2 +1.)/100000.*
     1 (80.-BE)**3.*SLARF*0.785/SFA
      IF(ISHAPE.NE.3) GO TO 1100
C     ---------------------------------------------
C     SHAPE IS BASKETHANDLE.  CHECK FOR COMPUTED ADVANCE RATE GREATER
C     THAN FOR CIRCLE OF SAME BE FOR STABILITY NUMBER = 0. IF GREATER,
C     SET ARTULT FOR BASKETHANDLE EQUAL TO MAXIMUM RATE FOR CIRCLE.
      IF(MEX.EQ.4) ART=0.00031*(80.-BE)**3.*SLARF
      IF(MEX.EQ.5) ART=0.0007975*(80.-BE)**3.*SLARF
      IF(ARTULT.GT.ART) ARTULT=ART
C     ---------------------------------------------
C     CHECK FOR SOFT GROUND FACE STABILIZATION BY GROUND INJECTIONS
 1100 IF(MSTAB.NE.3) GO TO 1200
C     GROUND INJECTIONS ARE USED.CHECK FOR APPLICATION FROM INSIDE SEG.
      NPLS=A(N,17)
```

(Continued)

```
      NPRS=A(N,18)
      ELNPLS=CNP(NPLS,2)
      ELNPRS=CNP(NPRS,2)
      ELSURF=(ELNPLS+ELNPRS)/2.
      ELAVG=(ELNPL+ELNPR)/2.
      SEGDEP=ELSURF-ELAVG
      IF(ISHAPE.NE.3) GO TO 1120
      IF(SEGDEP-BE/4. .GT.50.) GO TO 1150
      GO TO 1200
 1120 IF(SEGDEP-BE/2. .GT.50.) GO TO 1150
      GO TO 1200
C     GROUND INJECTIONS ARE MADE FROM WITHIN SEGMENT AND SLOWS ADVANCE
 1150 ARTULT=100./(100.+ARTULT)*ARTULT
      GO TO 1200
C     ------------------------------------------
C     CUT AND COVER
 1160 SIDESL=A(N,53)
      IF(SIDESL.GT.0.) GO TO 1180
C     VERTICAL CUT
      IF(ISUPPT.EQ.5) ARTULT=15.+7.*ATAN(3.-STABNO)
      IF(ISUPPT.EQ.6) ARTULT=18.+5.*ATAN(4.-STABNO)
      GO TO 1200
C     SLOPING CUT
 1180 DTRNCH=A(N,52)
      ARTULT=15000./(SIDESL*(20.+DTRNCH)+300.)
C     CONVERT COMPUTED ADVANCE RATES TO FEET/HOURS WORKED. INPUT RATES
C     ARE ALREADY IN FEET/HOURS WORKED
 1200 HOURS=TRDATA(NREACH,8)
      SHIFTS=1
      IF(HOURS.GE.12.) SHIFTS=2.
      IF(HOURS.GE.21.) SHIFTS=3.
      EFFAC=1.
      IF(HOURS/SHIFTS.GT.8.) EFFAC=1.0-0.01*(HOURS/SHIFTS-8.)**2.
      ARTULT=ARTULT*EFFAC*HOURS/24.
C     ------------------------------------------
  100 IF(TSEGL.LE.25.*(1.-BINSAR**2.)*ARTULT) GO TO 120
C     ULTIMATE ADVANCE RATE IS ATTAINED
      ARFAC=TSEGL/(25.*(1.-BINSAR)**2 *ARTULT+TSEGL)
      PINSAR=1.0
      GO TO 240
C     ULTIMATE ADVANCE RATE NEVER ATTAINED,SEGMENT TOO SHORT
  120 ARFAC=.5*(BINSAR+SQRT(BINSAR**2.+.04*TSEGL/ARTULT))
      PINSAR=SQRT(BINSAR**2.+.04*TSEGL/ARTULT)
  240 MEXP=MEX
C     COMPUTE AND STORE AVERAGE ADVANCE RATE FOR EACH SEGMENT
      A(N,49)=ARTULT
  300 A(N,8)=ARTULT*ARFAC
  400 CONTINUE
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     COMPUTE ADVANCE RATES IN SHAFT SEGMENTS
      DO 800 NSHAFT=1,NSMAX
      IF(SHAFT(NSHAFT,1).LE.-10.E29) GO TO 800
C     IF THE SHAFT IS A PORTAL, SKIP ADVANCE RATE COMPUTATIONS
      NPORT=SHAFT(NSHAFT,23)
      IF(NPORT.EQ.1) GO TO 800
      NSSEG1=SHAFT(NSHAFT,1)
      NSEGS=SHAFT(NSHAFT,4)
```

(Continued)

```
C       INITIALIZE VALUES
        PINSAR=0.
        MEXP=0
        DO 700 I=1,NSEGS
C       N=SEQUENCE NUMBER OF SHAFT SEGMENT
        N=I-1+NSSEG1
        MEX=B(N,7)
        SSEGL=B(N,35)
C       CHECK FOR SHAFT CONSTRUCTED IN CUT AND COVER
        IF(MEX.EQ.0) ARSULT=0.
        IF(MEX.EQ.0) GO TO 700
        STABNO=B(N,24)
C       D=DEPTH TO MIDPOINT OF SHAFT SEGMENT
        D=B(N,36)
        AR=B(N,8)
        RQD=B(N,6)
        GI=B(N,9)
C       FW IS AN INFLOW ADVANCE RATE FACTOR=1.0 IN DRY SHAFTS,.5 IN WET
        IF(GI.LT.1.) GO TO 440
C       SHAFT IS WET
        FW=0.5
        GO TO 450
C       SHAFT IS DRY
  440   FW=1.0
  450   BE=B(N,29)
        RS=B(N,5)
        IF(MEX.EQ.MEXP) GO TO 410
C       THIS IS FIRST SEGMENT IN SHAFT OR EXCAVATION METHOD HAS CHANGED
        BINSAR=0.
        GO TO 420
C       EXCAVATION IS SAME AS IN PREVIOUS SEGMENT
  410   BINSAR=PINSAR-.05
        IF(BINSAR.LT.0.) BINSAR=0.
  420   IF(AR.GT.0.) ARSULT=AR
        IF(AR.GT.0.) GO TO 500
C       ------------------------------------------
C       AN ULTIMATE ADVANCE RATE HAS NOT BEEN SPECIFIED,MUST COMPUTE ONE
C       COMPUTE SYSTEM ADVANCE RATES IN FEET/24 HOURS
C       CHECK FOR METHOD OF EXCAVATION
        IF(MEX.EQ.1 .OR. MEX.EQ.4) GO TO 1610
        IF(MEX.EQ.3) GO TO 1600
C       ------------------------------------------
C       MOLE IN ROCK
C       ADVANCE RATE EQUATION NOT GOOD FOR ROCK STRENGTH BELOW 3000 PSI
        IF(RS.LT.3000.) RS=3000.
        ARSULT=(5000000/(BE*RS))*(.5+RQD/200.)*FW
        GO TO 1650
C       MOLE IN SOFT GROUND
C       ------------------------------------------
 1600   ARSULT=(25.-4.*STABNO)*(1.-D/6000.)
        GO TO 1650
C       CONVENTIONAL EXCAVATION IN ROCK OR HAND EXCAVATION IN SOFT GROUND
 1610   IF(MEX.EQ.4) GO TO 1620
C       CONVENTIONAL EXCAVATION IN ROCK
        ARSULT=.05*FW*(RQD+100.)*(1.-D/6000.)
        GO TO 1650
C       HAND EXCAVATION IN SOFT GROUND
 1620   ISHAPS=SHAFT(NSHAFT,16)
```

(Continued)

```
      IF(ISHAPS.EQ.1) SFA=0.785
      IF(ISHAPS.EQ.2) SFA=1.0
      ARSULT=(10.-STABNO)*(1.-D/6000.)*0.785/SFA
C     ---------------------------------------------
C     CHECK FOR SOFT GROUND FACE STABILIZATION BY GROUND INJECTIONS
 1650 IF(MSTAB.EQ.3) GO TO 1660
      GO TO 1700
C     GROUND INJECTIONS ARE USED.CHECK FOR APPLICATION FROM INSIDE SEG.
 1660 IF(D.LE.200.) GO TO 1700
C     GROUND INJECTIONS ARE MADE FROM WITHIN SEGMENT AND SLOWS ADVANCE
      ARSULT=100./(100.+ARSULT)*ARSULT
C     CONVERT COMPUTED ADVANCE RATES TO FEET/HOURS WORKED. INPUT RATES
C     ARE ALREADY IN FEET/HOURS WORKED
 1700 HOURS=SHAFT(NSHAFT,17)
      ARSULT=ARSULT*HOURS/24.
C     ---------------------------------------------
  500 IF(SSEGL.LE.25.*(1.-BINSAR**2.)*ARSULT) GO TO 520
C     ULTIMATE ADVANCE RATE IS ATTAINED
      ARFAC=SSEGL/(25.*(1.-BINSAR)**2 *ARSULT+SSEGL)
      PINSAR=1.0
      GO TO 640
C     ULTIMATE ADVANCE RATE NEVER ATTAINED,SEGMENT TOO SHORT
  520 ARFAC=.5*(BINSAR+SQRT(BINSAR**2.+.04*SSEGL/ARSULT))
      PINSAR=SQRT(BINSAR**2.+.04*SSEGL/ARSULT)
  640 MEXP=MEX
C     COMPUTE AND STORE AVERAGE ADVANCE RATE FOR EACH SEGMENT
      B(N,39)=ARSULT
  700 B(N,8)=ARSULT*ARFAC
  800 CONTINUE
C     -------------------------------------------------------------
      RETURN
      END
      SUBROUTINE CONSTM (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     -------------------------------------------------------------
C     -------------------------------------------------------------
C     THIS SUBROUTINE CALCULATES SEGMENT CONSTRUCTION TIMES INCLUDING
C     TIME FOR LINING
C     -------------------------------------------------------------
C     -------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     -------------------------------------------------------------
C
C     CALCULATE CONSTRUCTION TIME FOR TUNNEL SEGMENTS
      DO 50 I=1,NTS
C     NEXT LINE SETS VERY HIGH LINING ADVANCE RATE FOR UNLINED AND
C     SHOTCRETED TUNNEL SEGMENTS WHICH RESULTS IN PRACTICALLY ZERO
C     CONSTRUCTION TIME IN THESE SEGMENTS. TIME FOR SHOTCRETING IS ZERO
C     BECAUSE IT IS PLACED IMMEDIATELY AFTER EXCAVATION
      AL=10.E30
      NTSTYP=A(I,16)
      NREACH=A(I,4)
      HOURS=TRDATA(NREACH,8)
      DAYS=TRDATA(NREACH,9)
```

(Continued)

```
      IF (NTSTYP.GT.1) GO TO 40
      LINING=A(I,10)
      IF(LINING.EQ.1) AL=3*HOURS
   40 AR=A(I,8)
      TSEGL=A(I,46)
   50 A(I,50)=(TSEGL/AR+TSEGL/AL)*7./DAYS
C     ------------------------------------------------------------
C     CALCULATE CONSTRUCTION TIME FOR SHAFT SEGMENTS
      DO 100 I=1,NSS
C     NEXT LINE SETS VERY HIGH LINING ADVANCE RATE FOR UNLINED AND
C     SHOTCRETED SHAFT  SEGMENTS WHICH RESULTS IN PRACTICALLY ZERO
C     CONSTRUCTION TIME IN THESE SEGMENTS. TIME FOR SHOTCRETING IS ZERO
C     BECAUSE IT IS PLACED IMMEDIATELY AFTER EXCAVATION
      AL=10.E30
      NSSTYP=B(I,15)
      NSHAFT=B(I,1)
      ISHAPS=SHAFT(NSHAFT,16)
      HOURS=SHAFT(NSHAFT,17)
      DAYS=SHAFT(NSHAFT,18)
      IF (NSSTYP.GT.1) GO TO 80
      LINING=B(I,10)
      IF(LINING.EQ.1) AL=2.*HOURS
   80 AR=B(I,8)
      SSEGL=B(I,35)
C     NO CONSTRUCTION TIME FOR CUT AND COVER OR DUMMY SHAFT
      IF(NSSTYP.EQ.3.OR.ISHAPS.EQ.0) AR=10.E30
  100 B(I,40)=(SSEGL/AR+SSEGL/AL)*7./DAYS
C     ------------------------------------------------------------
      RETURN
      END
      SUBROUTINE PUMPHT (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ------------------------------------------------------------
C     ------------------------------------------------------------
C
C     THIS SUBROUTINE COMPUTES PUMPING HEIGHTS FOR TUNNEL SEGMENTS
C
C     ------------------------------------------------------------
C     ------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ------------------------------------------------------------
      DO 200 I=1,NTS
      NREACH=A(I,4)
      NTSTYP=A(I,16)
      IF(NTSTYP.EQ.3) GO TO 100
C     ROCK OR SOFT GROUND
C     COMPUTE PUMPING HEIGHTS. PUMPING HEIGHT EQUALS SHAFT DEPTH OR
C     DIFFERENCE IN ELEVATION FROM TOP OF SHAFT TO MIDPOINT OF TUNNEL
C     SEGMENT, WHICHEVER IS GREATER
      NSHAFT=TRDATA(NREACH,1)
      NPTS=SHAFT(NSHAFT,2)
      ELTS=CNP(NPTS,2)
      NPL=A(I,2)
      NPR=A(I,3)
      ELNPL=CNP(NPL,2)
      ELNPR=CNP(NPR,2)
C     ELEVATION AT MIDPOINT OF TUNNEL SEGMENT
      ELAVG=(ELNPL+ELNPR)/2.
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(Continued)

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      PH=ELTS-ELAVG
C     SET HH EQUAL TO MUCK HOISTING HEIGHT(SHAFT DEPTH)
      HH=SHAFT(NSHAFT,8)
      IF(HH.GE.PH) PH=HH
      GO TO 150
C     CUT AND COVER
  100 D10=A(I,19)
      IF(D10.LE.0.005) PH=0
      IF(D10.LE.0.005) GO TO 150
      ELROCK=A(I,27)
      IWATER=A(I,23)
      ELIMP=A(I,24)
      NPLS=A(I,17)
      NPRS=A(I,18)
      ELNPLS=CNP(NPLS,2)
      ELNPRS=CNP(NPRS,2)
      ELSURF=(ELNPLS+ELNPRS)/2.
      DROCK=ELSURF-ELROCK
      DTRNCH=A(I,52)
      MEX=A(I,7)
      ISUPPT=A(I,26)
      ELWATR=A(I,14)
      DSLURY=A(I,38)
C     PH=THE SMALLER OF (ELSURF-ELIMP) AND DTRNCH, EXCEPT FOR SUMP
C     PUMPING, FOR WHICH PH=DTRNCH
      IF(DTRNCH.GE.ELSURF-ELIMP) PH=ELSURF-ELIMP
      IF(DTRNCH.LT.ELSURF-ELIMP) PH=DTRNCH
      IF(IWATER.EQ.0 .OR.ISUPPT.EQ.5 .AND. DROCK.LT.DTRNCH)PH=DTRNCH
      IF(IWATER.EQ.0.AND.ISUPPT.EQ.6.AND.DSLURY.GE.ELSURF-ELIMP) PH=0
      IF(ELWATR.LT.ELSURF-DTRNCH) PH=0
C     STORE PUMPING HEIGHT
  150 A(I,57)=PH
  200 CONTINUE
C     ------------------------------------------------------------------
      RETURN
      END
      SUBROUTINE PUMPRT (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     FLOW RATE TO BE PUMPED FROM TUNNEL AND DEWATERING FOR TUNNELS
C     AND SHAFTS.
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C
C     ******************************************************************
C     TUNNELS
C     ******************************************************************
C
      DO 400 NREACH=1,NTRMAX
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 400
      NRSEG1=TRDATA(NREACH,5)
      NSEGS=TRDATA(NREACH,6)
      NSEGSA=IABS(NSEGS)
```

(Continued)

```
C       INITIALIZE VALUES
        FLRT=0.
        TUBE=0.0
        ZZ=0.0
        Z=0.
        DO 300     I=1,NSEGSA
C       N=SEQUENCE NUMBER OF TUNNEL SEGMENT
        IF(NSEGS.GT.0) N=NRSEG1+I-1
        IF(NSEGS.LT.0) N=NRSEG1-I+1
        NTSTYP=A(N,16)
        PERM=A(N,25)
        D10=A(N,19)
        IWATER=A(N,23)
        NSTAB=A(N,31)
        BE=A(N,39)
        ELROCK=A(N,27)
        MEX=A(N,7)
        ELWATR=A(N,14)
        NPL=A(N,2)
        NPR=A(N,3)
        ELNPL=CNP(NPL,2)
        ELNPR=CNP(NPR,2)
        ELAVG=(ELNPL+ELNPR)/2.
        IF(NTSTYP.EQ.3) GO TO 200
C       ----------------------------------------------------------------
C       ROCK OR SOFT GROUND TUNNELS
C       ----------------------------------------------------------------
C       HEADING INFLOW AND RESIDUAL FLOW IN TUNNELS
        GI=A(N,9)
        ELBOTM=ELAVG-BE/2.
        ISHAPE=TRDATA(NREACH,3)
        IF(ISHAPE.EQ.3) ELBOTM=ELAVG-BE/4.
C       IF GROUNDWATER BELOW TUNNEL, GI = 0
        IF(ELWATR.LT.ELBOTM) GI=0.
        IF(NTSTYP.EQ.2) GO TO 140
C       ROCK TUNNELS
C       ESTABLISH RESIDUAL INFLOW(GPM/FT) AND INFLOW AT FACE FOR PUMPING
C       IN GPM
        IF(GI.GE.100.) GO TO 135
        GIR=0.001*GI
        GIF=GI
        GO TO 155
  135   GIR=0.1
        GIF=100.
        GO TO 155
C       SOFT GROUND TUNNELS
  140   GIF=GI
        GIR=0.
  155   A(N,60)=GIR
        R=FLRT
        TSEGL=A(N,45)
        FLRT=0.5*GIR*TSEGL
C       AVERAGE FLOW TO BE PUMPED AND CHARGED TO NTH SEGMENT
        FLOW=Z+R+FLRT+GIF
        A(N,59)=FLOW
        Z=FLOW-GIF
C       THE FOLLOWING WILL DETERMINE THE LENGTH OF PIPE REQUIRED
C       FOR THE SEGMENT WHEN PUMPING UPHILL.   IT IS ASSUMED THAT NO PIPE
```

(Continued)

```
C       IS REQUIRED WHEN THE THE WATER MAY RUN DOWN THE SEGMENT IN THE
C       DIRECTION OF THE EXIT SHAFT.
        NPL=A(N,2)
        NPR=A(N,3)
        ELEVD=CNP(NPR,2)-CNP(NPL,2)
C       SLOPE IS POSITIVE WHEN UPHILL IN THE DIRECTION OF HEADING ADVANCE
C        SS= SIGN OF THE SLOPE(ACTUAL VALUE IS IMMATERIAL)
        SS=ELEVD*NSEQS
C       ESTABLISH THE PIPE LENGTH REQUIRED
        PIPE=0.0
        IF(SS.LT.0) PIPE=0.5*TSEGL
C       DETERMINE THE CUMULATIVE PIPE LENGTHS REQUIRED
        A(N,58)=ZZ+TUBE+PIPE
        TUBE=PIPE
        ZZ=A(N,58)
        IF(NTSTYP.EQ.2) GO TO 160
C       ROCK TUNNELS
        GO TO 300
C
C
C       DEWATERING FOR SOFT GROUND TUNNELS
  160   IF(MSTAB.NE.2 .OR.ABS(PERM).LE. 0.0006) GO TO 250
        HEADV=0
        ELIMP=A(N,24)
C       IF DEWATERING METHOD USED, WATER TABLE ABOVE IMPERVIOUS LAYER, AND
C       WATER TABLE ABOVE ELAVG, THEN SET FOLLOWING VALUES
        IF(ELIMP.GE.ELBOTM) DRAWDN=ELWATR-ELIMP
        IF(ELIMP.LT.ELBOTM) DRAWDN=ELWATR-ELBOTM
        DIMP=ELBOTM-ELIMP
        GO TO 210
C       ---------------------------------------------------------------
C       CUT AND COVER DEWATERING
C       ---------------------------------------------------------------
  200   NPLS=A(N,17)
        NPRS=A(N,18)
        ELNPLS=CNP(NPLS,2)
        ELNPRS=CNP(NPRS,2)
        ELSURF=(ELNPLS+ELNPRS)/2.
        IF(D10.LE.0.005) GO TO 250
        ELIMP=A(N,24)
        DTRNCH=A(N,52)
        ISUPPT=A(N,26)
        PERM=ABS(PERM)
        IF(ISUPPT.NE.6 .OR. IWATER.EQ.1) GO TO 205
C       CHECK FOR SLURRY WALL PENETRATING IMPERVIOUS LAYER
        DSLURY=A(N,38)
        IF(DSLURY.GE.ELSURF-ELIMP.OR.DSLURY.GE.ELSURF-ELROCK) GO TO 250
  205   HEADV=-7.*(ALOG10(PERM)+1.)
        IF(HEADV.GT.21.) HEADV=21.
        IF(HEADV.LT.0.0) HEADV=0.
C       HEADV=0 FOR SUMP PUMPING
        IF(IWATER.EQ.0.OR. ISUPPT.EQ.5.AND.ELROCK.GT.ELSURF-DTRNCH)HEADV=0
        DRAWDN=DTRNCH-(ELSURF-ELWATR)
        DIMP=ELSURF-ELIMP-DTRNCH
        IF(DIMP.LT.0.0) DRAWDN=ELWATR-ELIMP
  210   IF(DIMP.LT.0.) DIMP=0
C       DEWATERING IS NOT NEEDED IF GROUNDWATER BELOW BOTTOM OF EXC.
        IF(DRAWDN.LE.0.) GO TO 250
```

(Continued)

```
      HEAD=DRAWDN+DIMP+HEADW
      PERM=ABS(PERM)
      FLOWDW=0.75*(0.73+0.27*(HEAD-DIMP)/HEAD)*(HEAD**2-DIMP**2)
     1/(HEAD-SQRT(HEAD*DIMP))*PERM
      IF(IWATER.EQ.0) GO TO 240
C     IS IT SOLDIER PILE WITH LAGGING AND ROCK LINE ABOVE TRENCH BOTTOM
      IF(ISUPPT.NE.5) GO TO 215
      IF(ELROCK.GT.ELSURF-DTRNCH) GO TO 240
C     WELL CAPACITY AND NUMBER OF WELLS
  215 IF(FLOWDW.LE.0.7) GO TO 220
      IF(FLOWDW.GT.400.) GO TO 230
      FLOWL=15.*FLOWDW**1.2
      WELLSP=15.*FLOWDW**0.2
      GO TO 235
  220 FLOWL=10
      WELLSP=10
      GO TO 235
  230 FLOWL=20000
      WELLSP=20000/FLOWDW
  235 WELLS=2./WELLSP
      GO TO 260
C     STORE FLOW FROM SUMP PUMPS
  240 A(N,61)=FLOWDW*2.
      WELLS=0
      A(N,68)=WELLS
      GO TO 300
  250 FLOWL=0
      WELLS=0
C     STORE WELL CAPACITY AND NUMBER OF WELLS PER FT OF TUNNEL
  260 A(N,61)=FLOWL
      A(N,68)=WELLS
  300 CONTINUE
  400 CONTINUE
C
C     ****************************************************************
C     SHAFTS-- DEWATERING ONLY
C     ****************************************************************
C
      DO 700 NSHAFT=1,NSMAX
      IF(SHAFT(NSHAFT,1).LT.-10.E29) GO TO 700
      NSSEG1=SHAFT(NSHAFT,1)
      NSEGS=SHAFT(NSHAFT,4)
      DO 600 I=1,NSEGS
      N=NSSEG1+I-1
      NSSTYP=B(N,15)
      PERM=B(N,23)
      MSTAB=B(N,25)
      MEX=B(N,7)
      BE=B(N,29)
      IF(NSSTYP.NE.2) GO TO 550
C     SOFT GROUND SHAFTS
      IF(MSTAB.NE.2 .OR. ABS(PERM).LE. 0.0006) GO TO 550
      ELWATR=B(N,13)
      NPB=B(N,4)
      ELNPB=CNP(NPB,2)
C     DEWATERING NOT NEEDED IF GROUNDWATER BELOW BOTTOM OF SHAFT SEGMENT
      IF(ELWATR.LE.ELNPB) GO TO 550
      NPTS=SHAFT(NSHAFT,2)
```

(Continued)

```
      ELSURF=CNP(NPTS,2)
      ISHAPS=SHAFT(NSHAFT,16)
      ELIMP=B(N,20)
      DRAWDN=ELWATR-ELNPB
      DIMP=ELNPB-ELIMP
      HEAD=DRAWDN+DIMP
      PERM=ABS(PERM)
      FLOWDW=0.75*(0.73+0.27*(HEAD-DIMP)/HEAD)*(HEAD**2-DIMP**2)
     1/(HEAD-SQRT(HEAD*DIMP))*PERM
      WELLS=3
      SFP=3.14
      IF(ISHAPS.EQ.2) SFP=4
      WELLSP=SFP*(BE+20.)/3.
      FLOWL=FLOWDW*WELLSP
      GO TO 560
C     ROCK OR CUT AND COVER SHAFTS
  550 FLOWL=0
C     STORE WELL CAPACITY
  560 B(N,42)=FLOWL
  600 CONTINUE
  700 CONTINUE
      RETURN
      END
      SUBROUTINE VOLUME (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
C     THIS SUBROUTINE COMPUTES THE EXCAVATED VOLUME PER LINEAR FOOT OF
C     TUNNEL AND SHAFT
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ------------------------------------------------------------------
C     TUNNEL VOLUME INCLUDING OVERBREAK IN SOLID CUBIC YARDS/FOOT
      DO 10 I=1,NTS
      NTSTYP=A(I,16)
C     CHECK IF     SEGMENT EXCAVATED BY CUT AND COVER
      IF(NTSTYP.EQ.3) GO TO 55
C     TUNNEL
      BOB=A(I,42)
      NREACH=A(I,4)
      ISHAPE=TRDATA(NREACH,3)
C     CHECK THE SHAPE OF TUNNEL
      IF(ISHAPE.EQ.1) SFA=0.785
      IF(ISHAPE.EQ.2) SFA=0.893
      IF(ISHAPE.EQ.3) SFA=0.425
      V=BOB**2*SFA/27.
      GO TO 10
C     ------------------------------------------------------------------
C     CUT AND COVER
   55 BE=A(I,39)
      DTRNCH=A(I,52)
      NPLS=A(I,17)
      NPRS=A(I,18)
      SIDESL=A(I,53)
C     COMPUTE THE DEPTH OF ROCK
```

(Continued)

```
      ELROCK=A(I,27)
      ELSURF=0.5*(CNP(NPLS,2)+CNP(NPRS,2))
      DROCK=ELSURF-ELROCK
C     COMPUTE THE EXCAVATED VOLUME IF CUT IS ENTIRELY IN SOIL
      VROCK=0.
      VSOIL=(BE+DTRNCH*SIDESL)*DTRNCH/27.
      IF(DROCK.GE.DTRNCH) GO TO 88
C     COMPUTE THE EXCAVATED VOLUME IF CUT IS IN PART SOIL-PART ROCK
      VROCK=BE*(DTRNCH-DROCK)/27.
      VSOIL=(BE+DROCK*SIDESL)*DROCK/27.
   88 V=VROCK+VSOIL
   10 A(I,51)=V
C     ---------------------------------------------------------------
C     SHAFT
      DO 20 I=1,NSS
      BOB=B(I,32)
      SFA=0.785
      NSHAFT=B(I,1)
      ISHAPS=SHAFT(NSHAFT,16)
      NSSTYP=B(I,15)
      IF(ISHAPS.EQ.2) SFA=1.
      V=0.
      IF(ISHAPS.EQ.0) GO TO 20
      IF(NSSTYP.NE.3) V=BOB**2*SFA/27.
   20 B(I,38)=V
      RETURN
      END
      SUBROUTINE EXCVOL (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ---------------------------------------------------------------
C     ---------------------------------------------------------------
C     CALCULATES THE EXCAVATED VOLUME TO EXIT FROM EACH SHAFT AND
C     LENGTH OF TRENCH TEMPORARILY LEFT OPEN IN CUT-AND-COVER EXCAVATION
C     ---------------------------------------------------------------
C     ---------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ---------------------------------------------------------------
C
C     INITIALIZE TOTAL EXCAVATED VOLUME
      DO 100 N=1,NSMAX
  100 SHAFT(N,9)=0.0
C     CALCULATE VOLUME FROM CUT AND COVER REACH
C     ---------------------------------------------------------------
      DO 1000 I=1,NTRMAX
      IF (TRDATA(I,1).LT.0) GO TO 1000
      NRSEG1=TRDATA(I,5)
      NTSTYP=A(NRSEG1,16)
      IF(NTSTYP.NE.3) GO TO 1000
      NSHAFT=TRDATA(I,1)
      NSEGS=TRDATA(I,6)
      DAYS=TRDATA(I,9)
      NSEGSA=IABS(NSEGS)
      VTEXC=0.
      VTBOX=0.
      PINSAR=0.
      M=NRSEG1
```

(Continued)

```
      L=0
      VTDS=0.
 1100 T1=0.
      L=L+1
      TSEGL =A(M,45)
      V     =A(M,51)
      VBOX  =A(M,54)
      AR    =A(M, 8)
      ARTULT=A(M,49)
      LINING=A(M,10)
      CTTS1 =TSEGL/AR
C     ADVANCE RATE FACTOR AT END POINTS OF SEGMENT
      BINSAR=PINSAR-0.05
      IF(BINSAR.LT.0.) BINSAR=0.
      TMULT=(1.-BINSAR)/0.02
      PINSAR=BINSAR+0.02*CTTS1
      IF(PINSAR.GT.1.)PINSAR=1.
C     TIME REQUIRED FOR TRENCH TO BE LEFT OPEN
      IF(LINING.EQ.1) TIMEOP=30.*DAYS/7.+10.
      IF(LINING.EQ.3) TIMEOP=10.
      VTEXC=VTEXC+V*TSEGL
      VTBOX=VTBOX+VBOX*TSEGL
      IF(CTTS1.GT.TIMEOP) T1=CTTS1-TIMEOP
C     COMPUTE THE LENGTH OF OPEN WITHOUT BACKFILL
 1200 IF(CTTS1.LE.TMULT) OPENT=ARTULT*(CTTS1-T1)*(BINSAR+0.01*(CTTS1+T1)
     1 )
      IF(CTTS1.GT.TMULT) OPENT=ARTULT*(BINSAR*(TMULT-T1)+0.01*(TMULT**2
     1 -T1**2)+CTTS1-TMULT)
      IF(T1.GT.TMULT) OPENT=ARTULT*(CTTS1-T1)
C     CALCULATE VOLUME OF DISPOSAL AND BACKFILL
      VTDST=(0.1*VTEXC+VTBOX+(V-VBOX)*OPENT)/1.1
      VBFT=(V-VBOX)*OPENT
      T2=TIMEOP-CTTS1+T1
      PIN2=PINSAR
      N=M+NSEGS/NSEGSA
      LL=L+1
C     CHECK IF THE NEXT SEGMENT IS INVOLVED
      IF(T2.LE.0.) GO TO 1500
C     CHECK FOR END OF REACH
 1300 IF(LL.GT.NSEGSA) GO TO 1500
      TSEGL =A(N,45)
      V2    =A(N,51)
      VBOX2 =A(N,54)
      AR    =A(N, 8)
      ARTU2 =A(N,49)
      CTTS2 =TSEGL/AR
      BIN2=PIN2-0.05
      IF(BIN2.LT.0.) BIN2=0.
C     CHECK IF MORE SEGMENTS INVOLVED
      IF(T2.LE.CTTS2) GO TO 1400
      LL=LL+1
      T2=T2-CTTS2
      N=N+NSEGS/NSEGSA
      VTDST=VTDST+V2*TSEGL
      VBFT=VBFT+(V2-VBOX2)*TSEGL
      PIN2=BIN2+0.02*CTTS2
      IF(PIN2.GT.1.) PIN2=1.
      OPENT=OPENT+TSEGL
```

(continued)

```
      GO TO 1300
 1400 TMULT2=(1.-BIN2)/0.02
C     COMPUTE LENGTH WITHOUT BACKFILL IN THE LAST SEGMENT OF OPEN
      IF(T2.LE.TMULT2) OPENT2=ARTU2*T2*(BIN2+0.01*T2)
      IF(T2.GT.TMULT2) OPENT2=ARTU2*(BIN2*TMULT2+0.01*TMULT2**2
     1 +T2-TMULT2)
C     COMPUTE VOLUME OF DISPOSAL AND BACKFILL
      VTDST=VTDST+V2*OPENT2
      VBFT=VBFT+(V2-VBOX2)*OPENT2
      OPENT=OPENT+OPENT2
C     MAXIMUM VOLUME IN LENGTH 'OPEN'
 1500 IF(VTDS.GT.VTDST) GO TO 1600
      VTDS=VTDST
      VBF=VBFT
      OPEN=OPENT
C     CHECK IF LAST SEGMENT OF REACH
 1600 IF (L.GE.NSEGSA) GO TO 2100
      IF(LL.GT.NSEGSA) GO TO 1700
      T1=T1+1.
      IF(T1.LT.CTTS1) GO TO 1200
      M=M+NSEGS/NSEGSA
      GO TO 1100
C     ------------------------------------------------------------
C     COMPUTE THE TOTAL VOLUME OF EXCAVATION AND BOX IN A REACH
 1700 MM=M+1
      DO 2000 J=MM,N
      TSEGL=A(J,45)
      V=A(J,51)
      VBOX=A(J,54)
      VTEXC=VTEXC+V*TSEGL
 2000 VTBOX=VTBOX+VBOX*TSEGL
 2100 VDS=VTDS/VTEXC
      SHAFT(NSHAFT,9)=SHAFT(NSHAFT,9)+VTDS
C     BACKFILL VOLUME
      VBACDS=VBF/1.1/(VTEXC-VTBOX)
      VBACEX=0.909-VBACDS
C     STORE VALUES IN ARRAY
      TRDATA(I,16)=OPEN
      TRDATA(I,21)=VDS
      TRDATA(I,22)=VBACEX
      TRDATA(I,23)=VBACDS
 1000 CONTINUE
C     ------------------------------------------------------------
C     CALCULATE VOLUME FROM TUNNEL SEGMENT
      DO 200 N=1,NTS
      NREACH=A(N,4)
      NSHAFT=TRDATA(NREACH,1)
      NTSTYP=A(N,16)
      IF(NTSTYP.EQ.3) GO TO 200
      V=A(N,51)
      TSEGL=A(N,45)
      SHAFT(NSHAFT,9)=SHAFT(NSHAFT,9)+V*TSEGL
  200 CONTINUE
C     ------------------------------------------------------------
C     CALCULATE VOLUME FROM SHAFT SEGMENT
      DO 300 N=1,NSS
      NSHAFT=B(N,1)
      NSSTYP=B(N,15)
```

(Continued)

```
      IF(NSSTYP.EQ.3) GO TO 300
      U=B(N,38)
      SSEGL=B(N,35)
      SHAFT(NSHAFT,9)=SHAFT(NSHAFT,9)+U*SSEGL
  300 CONTINUE
C     ------------------------------------------------------------------
      RETURN
      END
      SUBROUTINE MUCKLD(A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CALCULATES REQUIRED MUCK LOADING RATES IN EACH SEGMENT AND
C     MAXIMUM RATE IN EACH REACH OR SHAFT BASED ON ULTIMATE ADVANCE RATE
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ------------------------------------------------------------------
C     MUCK LOADING RATE IN TUNNEL SEGMENTS AND MAXIMUM RATE IN REACH
      DO 400 NREACH=1,NTRMAX
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 400
C
      HOURS=TRDATA(NREACH,8)
      NRSEG1=TRDATA(NREACH,5)
      NSEGS=TRDATA(NREACH,6)
      NSEGSA=IABS(NSEGS)
C
      RMLMAX=0
C
      DO 300  I=1,NSEGSA
C     N=SEQUENCE NUMBER OF TUNNEL SEGMENT
      IF(NSEGS.GT.0) N=NRSEG1+I-1
      IF(NSEGS.LT.0) N=NRSEG1-I+1
      NTSTYP=A(N,16)
      IF (NTSTYP.EQ.3) GO TO 300
      MEX=A(N,7)
      U=A(N,51)
      ARTULT=A(N,49)
C     CALCULATE  MUCK LOADING RATE
      IF(MEX.EQ.1) GO TO 200
      RML=3.*U*ARTULT/HOURS
      GO TO 250
  200 IF(5.*HOURS/ARTULT.GE.2) RML=5.*U
      IF(5.*HOURS/ARTULT.LT.2.) RML=2.*U*ARTULT/HOURS
  250 IF(RMLMAX.LT.RML) RMLMAX=RML
      A(N,48)=RML
  300 CONTINUE
C
  350 TRDATA(NREACH,7)=RMLMAX
  400 CONTINUE
C     ------------------------------------------------------------------
C     MUCK LOADING RATE IN SHAFT SEGMENTS AND MAXIMUM RATE IN SHAFTS
      DO 800 NSHAFT=1,NSMAX
      IF(SHAFT(NSHAFT,1).LE.-10.E29) GO TO 800
C
      HOURS=SHAFT(NSHAFT,17)
```

(Continued)

```
      NSSEQ1=SHAFT(NSHAFT,1)
      NSEGS=SHAFT(NSHAFT,4)
C
      RMLMAX=0
C
      DO 700 I=1,NSEGS
      N=I-1+NSSEQ1
C     N=SEQUENCE NUMBER OF SHAFT SEGMENT
C     CHECK FOR CUT AND COVER OR DUMMY SHAFT - NO RML COMPUTED
      MEX=B(N,7)
      IF(MEX.EQ.0) GO TO 700
      V=B(N,38)
      ARSULT=B(N,39)
      IF(MEX.EQ.1) GO TO 600
      RML=3.*V*ARSULT/HOURS
      GO TO 650
  600 IF(5.*HOURS/ARSULT.GE.12.) RML=5.*V/6.
      IF(5.*HOURS/ARSULT.LT.12.) RML=2.*V*ARSULT/HOURS
  650 IF(RMLMAX.LT.RML) RMLMAX=RML
      B(N,37)=RML
  700 CONTINUE
C
  750 SHAFT(NSHAFT,10)=RMLMAX
  800 CONTINUE
C     -----------------------------------------------------------------
      RETURN
      END
      SUBROUTINE AIRLOK(A,B,CNP,SHAFT,TRDATA,CUMSL,NTSMAX,NSSMAX,NPMAX,
     1NSMAX,NTRMAX)
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
C     THIS SUBROUTINE DETERMINES THE LOCATIONS OF AIR LOCKS AND COOLING
C     PLANT IN A REACH AND COMPUTES THE COOLING AND VENTILATION
C     REQUIREMENTS OF TUNNEL SEGMENTS AND MAXIMUM REQUIREMENT IN A REACH
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23),CUMSL(NPMAX)
C     -----------------------------------------------------------------
      DO 200 J=1,NTRMAX
      IF(TRDATA(J,1).LT.0) GO TO 200
      ISHAPE=TRDATA(J,3)
      IF(ISHAPE.EQ.0) GO TO 200
C     INITIALIZATION
      NRSEG1=TRDATA(J,5)
      NSEGS=TRDATA(J,6)
      NSHAFT=TRDATA(J,1)
      DTC=0.
      QT=0.
      AIRTEM=SHAFT(NSHAFT,11)
      NSEGSA=IABS(NSEGS)
      KOOL=0
      DTCA=0.
      CAUT=0.
      M=0
      N1=1
      NPBS=SHAFT(NSHAFT,3)
```

(Continued)

```
      HH=SHAFT(NSHAFT,8)
      NPLOCK=0
      IF(ISHAPE.EQ.1) SFA=0.785
      IF(ISHAPE.EQ.2) SFA=0.893
      IF(ISHAPE.EQ.3) SFA=0.425
C     DETERMINE THE STATION OF THE FARTHEST    POINT OF COMPRESSED AIR
C     SEGMENT IN A REACH
      DO 50 N=1,NSEGSA
      IF(NSEGS.LT.0) GO TO 10
C     I = SEQUENCE NUMBER OF SEGMENT
      I=NRSEG1+N-1
      NPFEND=A(I,3)
      GO TO 20
   10 I=NRSEG1-N+1
      NPFEND=A(I,2)
   20 MSTAB=A(I,31)
      TSEGL=A(I,45)
      IF(MSTAB.NE.1) GO TO 50
      DTCA=DTCA+TSEGL
      CUMFCA=CUMSL(NPFEND)
   50 CONTINUE
C     -----------------------------------------------------------------
C     DETERMINE THE LOCATION OF AIR LOCK FOR A SEGMENT IN COMPRESSED AIR
      DO 100 N=1,NSEGSA
      IF (NSEGS.LT.0) GO TO 60
      I=NRSEG1+N-1
      NPFEND=A(I,3)
      NPREND=A(I,2)
      NPS=A(I,17)
      GO TO 65
   60 I=NRSEG1-N+1
      NPFEND=A(I,2)
      NPREND=A(I,3)
      NPS=A(I,18)
   65 BE=A(I,39)
      PH=A(I,57)
      TSEGL=A(I,45)
      DM=A(I,46)
      RTEMP=A(I,12)
      MSTAB=A(I,31)
      IF(MSTAB.NE.1) GO TO 85
      PERM=A(I,25)
      D10=SQRT(10.*ABS(PERM))
      IF(D10.LE.0.005) D10=0.005
C     -----------------------------------------------------------------
      M=M+1
C     COMPUTE VENTILATION QUANTITY FOR THE SEGMENT IN COMPRESSED AIR
      CAV=(28.5+10.*ALOG10(D10))*SFA*BE**2
C     CHECK THE FIRST COMPRESSED AIR SEGMENT
      IF(M.NE.1) GO TO 70
C     CHECK IF COOLING PLANT FOR FIRST AIR LOCK TO BE MOVED FROM
C     SHAFT TO ABOVE THE LOCK
      IF(ABS(CUMFCA-CUMSL(NPBS))+HH.LE.12000..AND.DTC.GT.0.) GO TO 75
      GO TO 71
C     CHECK SEPARATION BETWEEN TWO COMPRESSED AIR SEGMENTS
   70 IF(ABS(CUMSL(M-1)-CUMSL(NPREND)).GT.5000..AND.
     1 ABS(CUMFCA-CUMSL(NPREND)).GT.2000.) GO TO 71
C     CHECK THE STATIONING OF THE SEGMENT END POINT TO DETERMINE THE
```

(Continued)

```
C     POSITION THE AIR LOCK
      LOCK=IABS(NPLOCK)
      IF(ABS(CUMSL(NPFEND)-CUMSL(LOCK))+DTHLOK.LE.10000.) GO TO 80
      IF(ABS(CUMFCA-CUMSL(LOCK))+DTHLOK.LE.12000.) GO TO 80
C     STORE THE HEAT EXCHANGE AND COMPRESSED AIR QUANTITIES WITHIN
C     COMPRESSED AIR SEGMENTS.
   71 N2=N-1
      DO 72 NN=N1,N2
      II=NRSEG1+(NN-1)*NSEGS/NSEGSA
      A(II,35)=CAVT
   72 A(II,37)=QT
      N1=N
      CAVT=0.
      KOOL=1
C     KOOL  = INDICATOR FOR THE LOCATION OF COOLING PLANT
      QT=0.
C     SET UP THE LOCK
   75 NPLOCK=NPREND
      DTHLOK=CNP(NPS,2)-CNP(NPLOCK,2)
      DLOCK=ABS(CUMSL(NPLOCK)-CUMSL(NPBS))
C     COMPUTE THE LENGTH OF PIPE FOR COOLING IN COMPRESSED AIR SEGMENT
   80 IF(KOOL.EQ.0) PUMPLT=5280.*DM+HH
      IF(KOOL.EQ.1) PUMPLT=5280.*DM-DLOCK+DTHLOK
C     NPLOCK = NEGATIVE IF COOLING PLANT OF FIRST AIR LOCK MOVED FROM
C     SHAFT TO TOP OF LOCK
      IF (KOOL.EQ.1.AND.N.EQ.1.AND.DTC.GT.0.) NPLOCK=-NPLOCK
C     COMPUTE THE QUANTITY OF COOLED AIR REQUIRED IN COMPRESSED AIR
C     SEGMENT
      Q=CAV*(74.00+0.031*PUMPLT)+SQRT(CAV)*PUMPLT
     1 *(0.23+0.0454*(RTEMP-85.))+239.*PUMPLT
      IF(CAV.GT.CAVT) CAVT=CAV
      M=NPFEND
      GO TO 90
C     ----------------------------------------------------------------
C     COMPUTE QUANTITY OF COOLED AIR REQUIRED IN FREE AIR SEGMENT
   85 IF (KOOL.EQ.1) DM=DM-DLOCK/5280.
      Q=SFA*BE**2*(150.*PH /(AIRTEM+460.)+0.03*5280.*DM+54.*AIRTEM
     1 -4000.)+5280.*DM*SQRT(SFA*BE**2)*(0.35*RTEMP-29.)+2.4*DM*5280.
   90 IF(Q.LE.0.) GO TO 95
      DTC=DTC+TSEGL
      IF(Q.GT.QT) QT=Q
C     STORE THE LOCK POSITION AND HEAT EXCHANGE QUANTITY
   95 A(I,38)=Q
      A(I,36)=NPLOCK
C     CHECK THE LAST SEGMENT IN A REACH
      IF (N.NE.NSEGSA) GO TO 100
      DO 99 NN=N1,N
      II=NRSEG1+(NN-1)*NSEGS/NSEGSA
      A(II,35)=CAVT
   99 A(II,37)=QT
  100 CONTINUE
      TRDATA(J,14)=DTCA
      TRDATA(J,15)=DTC
  200 CONTINUE
      RETURN
      END
      SUBROUTINE CALCS (A,B,CNP,SHAFT,TRDATA,NTSMAX,NSSMAX,NPMAX,NSMAX,
     1NTRMAX)
```

(Continued)

```
C     ------------------------------------------------------------------
C     THIS SUBROUTINE OUTPUTS CALCULATED TUNNEL AND SHAFT DATA
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
      COMMON /BASIC/  NSS,NTS
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON/F/ IERROR,ISTOP
      DIMENSION A(NTSMAX,68),B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23)
C     ******************************************************************
C     REFER TO COMMENT ON DOUBLE PRECISION LITERALS IN SUBROUTINE 4.
      DOUBLE PRECISION TNONE,AIRPRS,DEWATR,GRDINJ,SUMP,STABIL
C     ******************************************************************
      DATA TNONE/' NONE '/,AIRPRS/'AIRPRS'/,DEWATR/'DEWATR'/,
     1GRDINJ/'GRDINJ'/,SUMP/' SUMP '/
C     ------------------------------------------------------------------
C
C     OUTPUT CALCULATED TUNNEL DATA
C
      ITYPE=1
      NLINES=40
      IPR=0
C     N=SEGMENT SEQUENCE NUMBER
      DO 100 N=1,NTS
      NLINES=NLINES+1
      IF(LIST(4).EQ.1) GO TO 10
      IF(NLINES.LT.40) GO TO 10
      NLINES=0
      WRITE(LO,3000)
      WRITE(LO,3010)
   10 NREACH=A(N,4)
      NPL=A(N,2)
      NPR=A(N,3)
      NTSEG=A(N,1)
      BE= A(N,39)
      NTSTYP=A(N,16)
      IF(NTSTYP.EQ.3) GO TO 40
C     ------------------------------------------------------------------
      ISHAPE=TRDATA(NREACH,3)
      MTM=TRDATA(NREACH,4)
      HSLOPE=A(N,47)
      IF(MTM.NE.3) GO TO 20
C     CHECK FOR MAXIMUM SLOPE FOR TRAIN
      IF(ABS(HSLOPE).LE.0.05) GO TO 30
      WRITE(LO,1020) NTSEG,NREACH
      NLINES=NLINES +1
      IERROR=1
      GO TO 30
   20 IF(MTM.NE.1) GO TO 30
C     ------------------------------------------------------------------
C     CHECK FOR TUNNEL CROWN HIGH ENOUGH TO HANDLE A TRUCK
      IF(ISHAPE.LE.2.AND.BE.LT.16.) GO TO 25
      IF(ISHAPE.EQ.3.AND.BE.LT.30.) GO TO 25
      GO TO 30
   25 WRITE(LO,1021) NTSEG,NREACH
      NLINES=NLINES +1
      IERROR=1
   30 CONTINUE
```

(Continued)

```
C     ------------------------------------------------------------------
C     CHECK FOR TOO STEEP A SLOPE FOR MUCK HAUL BY TRUCK OR CONVEYOR
      IF(ABS(MSLOPE).LE.0.26) GO TO 32
      WRITE(LO,1023) NTSEG,NREACH
      NLINES=NLINES+1
      IERROR=1
C     ------------------------------------------------------------------
C     CHECK SOFT GROUND TUNNEL FOR ALL TRUCK IN COMPRESSED AIR SEGMENTS
   32 IF(NTSTYP.EQ.1) GO TO 40
      MSTAB=A(N,31)
      MUST=A(N,32)
      IF(MSTAB.NE.1) GO TO 40
      IF(MUST.LT.3.OR.MTM.NE.1) GO TO 35
      IERROR=1
      WRITE(LO,1025) NTSEG,NREACH
      NLINES=NLINES+1
   35 CONTINUE
      IF(MUST.LT.3.AND.MTM.EQ.1) WRITE(LO,1030) NTSEG,NREACH
      IF(MUST.LT.3.AND.MTM.EQ.1) MTM=4
      TRDATA(NREACH,4)=MTM
   40  CONTINUE
      IF(LIST(4).EQ.1) GO TO 70
C     ------------------------------------------------------------------
C     CONVERT NODAL POINT STATIONING TO INTEGER VALUES
      STA=CNP(NPL,1)
      ISTA=STA/100.
      ISTA2=STA-ISTA*100
      ITENS=ISTA2/10.
      IHUNS=ISTA2-ITENS*10
      IHUNS=IABS(IHUNS)
      ICTTS=A(N,50)
      LSEGL=A(N,45)
      IPRML=TRDATA(NREACH,7)
      IFL=A(N,59)
      IPH=A(N,57)
      BOB=A(N,42)
      ARTULT=A(N,49)
      TL=A(N,11)*12.
      BFT=TRDATA(NREACH,2)
      AR=A(N,8)
C     ------------------------------------------------------------------
C     EXCAVATED VOLUMES
   50 VSOIL=0.0
      VROCK=0.0
      V=A(N,51)
      IF(NTSTYP.EQ.1) VROCK=V
      IF(NTSTYP.EQ.2) VSOIL=V
      IF(NTSTYP.LT.3) GO TO 60
C     CUT AND COVER
      DTRNCH=A(N,52)
      NPLS=A(N,17)
      NPRS=A(N,18)
      SIDESL=A(N,53)
C     COMPUTE THE DEPTH OF ROCK
      ELROCK=A(N,27)
      ELSURF=0.5*(CNP(NPLS,2)+CNP(NPRS,2))
      DROCK=ELSURF-ELROCK
C     COMPUTE THE EXCAVATED VOLUME IF CUT IS ENTIRELY IN SOIL
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(Continued)

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      VROCK=0.                                                          057270 0000
      VSOIL=(BE+DTRNCH*SIDESL)*DTRNCH/27.                               057280 0000
      IF(DROCK.GE.DTRNCH) GO TO 60                                      057290 0000
C     COMPUTE THE EXCAVATED VOLUME IF CUT IS IN PART SOIL-PART ROCK     057300 0000
      VROCK=BE*(DTRNCH-DROCK)/27.                                       057310 0000
      VSOIL=(BE+DROCK*SIDESL)*DROCK/27.                                 057320 0000
   60 IVTR=VROCK                                                        057330 0000
      IVTS=VSOIL                                                        057340 0000
C     ------------------------------------------------------------------ 057350 0000
      IF(NTSTYP.EQ.1) GO TO 70                                          057360 0000
      ISUPPT=A(N,26)                                                    057370 0000
      GAMMA=A(N,22)                                                     057380 0000
      PERM=ABS(A(N,25))                                                 057390 0000
      IFLOWL=A(N,61)                                                    057400 0000
      STABNO=A(N,30)                                                    057410 0000
      IF(NTSTYP.EQ.3) GO TO 65                                          057420 0000
C     ------------------------------------------------------------------ 057430 0000
C     SOFT GROUND TUNNEL                                                057440 0000
      AIRPR=A(N,33)                                                     057450 0000
      MSTAB=A(N,31)                                                     057460 0000
      IF(MSTAB.EQ.0) STABIL=TNONE                                       057470 0000
      IF(MSTAB.EQ.1) STABIL=AIRPRS                                      057480 0000
      IF(MSTAB.EQ.2) STABIL=DEWATR                                      057490 0000
      IF(MSTAB.EQ.3) STABIL=GRDINJ                                      057500 0000
      GO TO 70                                                          057510 0000
C     ------------------------------------------------------------------ 057520 0000
C     CUT AND COVER                                                     057530 0000
   65 VL   =A(N,55)                                                     057540 0000
      SIDESL=A(N,53)                                                    057550 0000
      WELLS=A(N,68)                                                     057560 0000
      DSLURY=0.0                                                        057570 0000
      SPDLT=0.0                                                         057580 0000
      STABIL=TNONE                                                      057590 0000
      IF(IFLOWL.GT.0) STABIL=SUMP                                       057600 0000
      IF(IFLOWL.GT.0.AND.WELLS.GT.0.0) STABIL=DEWATR                    057610 0000
      OPEN=TRDATA(NREACH,16)                                            057620 0000
      VBACEX=TRDATA(NREACH,22)                                          057630 0000
      VBACDS=TRDATA(NREACH,23)                                          057640 0000
      V=A(N,51)                                                         057650 0000
      VBOX=A(N,54)                                                      057660 0000
      BACKFL=(VBACEX+VBACDS)*(V-VBOX)*1.1                               057670 0000
C     CHECK IF SEGMENT IN SAME REACH                                    057680 0000
   70 IF(IPR.EQ.NREACH) GO TO 85                                        057690 0000
C     ------------------------------------------------------------------ 057700 0000
C     CALCULATE CONSTRUCTION TIME FOR THE REACH  (CTR)                  057710 0000
      NSEGS=TRDATA(NREACH,6)                                            057720 0000
      NSEGSA=IABS(NSEGS)                                                057730 0000
      HOURS=TRDATA(NREACH,8)                                            057740 0000
      DAYS=TRDATA(NREACH,9)                                             057750 0000
      CTR=0.0                                                           057760 0000
      ALOCK=0.0                                                         057770 0000
      ICTR=0                                                            057780 0000
      MEXP=0                                                            057790 0000
      SETUSH=0.0                                                        057800 0000
      SETUPM=0.0                                                        057810 0000
      SETUPR=0.0                                                        057820 0000
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(Continued)

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      TIMEDW=0.0
      TIMECR=0.0
      L=0
      DO 730 I=1,NSEGSA
      NN=N+I-1
      CTTS=A(NN,50)
      MEX=A(NN,7)
  702 IF(MEX.GE.6) GO TO 705
C     SOFT GROUND OR ROCK TUNNEL
      CALL SETUP(MEX,MEXP,SETUSH,SETUPM,SETUPR,ITYPE)
      IF(I.EQ.1) NPLOCK=A(NN,36)
      IF (A(NN,36).EQ.0) GO TO 730
C     CALCULATE NUMBER OF AIR LOCK SETUPS
      IF(ALOCK.LT.1.) GO TO 703
      IF (A(NN,36).EQ.NPLOCK) GO TO 730
      ALOCK=ALOCK+0.25
      GO TO 704
  703 ALOCK=1.
  704 NPLOCK=A(NN,36)
      GO TO 730
C     -----------------------------------------------------------------------------------------------
C     CUT AND COVER
  705 ELWATR =A(NN,14)
      D10=A(NN,19)
      IWATER=A(NN,23)
      ELIMP=A(NN,24)
      PERM=A(NN,25)
      FLOWL=A(NN,61)
      NPLS=A(NN,17)
      NPRS=A(NN,18)
      DTRNCH=A(NN,52)
      ELROCK=A(NN,27)
      ELNPLS=CNP(NPLS,2)
      ELNPRS=CNP(NPRS,2)
C     CALULATE THE EXTRA CURING TIME FOR CIP CONCRETE
      IF(L.LT.0) GO TO 708
      MM=NN
      IF(NSEGS.GT.0) MM=N+NSEGSA-I
      LINING=A(MM,10)
      IF(LINING.EQ.1) GO TO 707
      CTR=CTR+CTTS
      GO TO 708
  707 TIMECR=30.-CTR
      IF(TIMECR.LT.0.) TIMECR=0.
      L=-1
  708 IF(D10.LE.0.005.OR.IWATER.EQ.0) GO TO 730
      IF(PERM.GT.0.0.AND.D10.GT.0.08) GO TO 709
      IF(PERM.LT.0.0.AND.ABS(PERM).GT.0.0006) GO TO 709
      TIMEDW=30.
      GO TO 730
  709 ELSURF=0.5*(ELNPLS+ELNPRS)
      DWATER=ELSURF-ELWATR
      DRAWDN=DTRNCH-DWATER
      DROCK=ELSURF-ELROCK
      PERM=ABS(PERM)
      IF(DROCK.LT.DTRNCH.AND.ISUPPT.EQ.5) GO TO 730
C     CHECK IF WATER TABLE BELOW BASE OF CUT
      IF(DRAWDN.LE.0.) GO TO 730
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      DIMP=ELSURF-ELIMP-DTRNCH
C     CHECK IF IMPERVIOUS LAYER ABOVE BASE OF CUT
      IF(DIMP.GE.0.0) GO TO 710
      DRAWDN=ELWATR-ELIMP
      DIMP=0.0
  710 HEADV=-7.*(ALOG10(PERM)+1.)
C     CHECK IF VACUUM HEAD GREATER THAN 21 FEET
      IF(HEADV.GT.21.) HEADV=21.0
C     CHECK IF VACUUM HEAD LESS THAN 0 FEET
      IF(HEADV.LT.0.0) HEADV=0.0
      HEAD=DRAWDN+HEADV+DIMP
      PIPED=0.5*FLOWL**0.4
C     MINIMUM PIPE SIZE
      IF(PIPED.LT.1.) PIPED=1.
C     DRAWDOWN  TIME
      EXPT=2.5*DRAWDN*ALOG10(240.*(HEAD-SQRT(HEAD*DIMP))/PIPED)/(DRAWDN
     1+HEADV)/(0.73+0.27*(DRAWDN+HEADV)/HEAD)-5.0
      TIMET=0.00267*PIPED**2*10.**EXPT/PERM/DRAWDN
C     CHECK FOR MAXIMUM SEGMENT DEWATERING TIME IN REACH
      IF(TIMEDW.LT.TIMET) TIMEDW=TIMET
  730 ICTR=ICTR+CTTS
      ICTR=ICTR+14.*SETUSH+28.*SETUPM+7.*SETUPR+14.*ALOCK
C     ------------------------------------------------------------------
C     CHECK FOR CUT AND COVER REACH
      NTSTYP=A(N ,16)
      IF(NTSTYP.EQ.3) GO TO 740
      TRDATA(NREACH,10)=SETUSH
      TRDATA(NREACH,11)=SETUPM
      TRDATA(NREACH,12)=SETUPR
      GO TO 750
  740 ICTR=ICTR+70./DAYS+TIMECR+TIMEDW
      TRDATA(NREACH,14)=TIMEDW
  750 IF(LIST(4).EQ.1) GO TO 100
      WRITE(LO,2222)
      NLINES=NLINES+1
      IF(NTSTYP.EQ.1) GO TO 73
      PERM=ABS(A(N,25))
      GAMMA=A(N,22)
      IFLOWL=A(N,61)
   73 CONTINUE
C     ------------------------------------------------------------------
      IF(NTSTYP.EQ.3) GO TO 80
C     ROCK OR SOFT GROUND TUNNEL
      WRITE(LO,3001) NREACH,NTSEG,ISTA,ITENS,IHUNS,LSEGL,BFT,BE,BOB,AR,
     1ARTULT,TL,IVTS,IVTR  ,IFL,IPH,ICTTS,ICTR,IPRML,HOURS,DAYS
      IF(NTSTYP.EQ.1) GO TO 100
```

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```
C     -----------------------------------------------------------------
C     SOFT GROUND TUNNEL
      IF(MSTAB.NE.1) GO TO 75
C     AIR LOCK NODAL POINTS
      NPLOCK=A(N,36)
      STA=CNP(NPLOCK,1)
      ISTA=STA/100.
      ISTA2=STA-ISTA*100
      ITENS=ISTA2/10.
      IHUNS=ISTA2-ITENS*10
      IHUNS=IABS(IHUNS)
      WRITE(LO,3002) ISTA,ITENS,IHUNS,STABNO,STABIL,AIRPR,IFLOWL,GAMMA,
     1PERM
      NLINES=NLINES+1
      GO TO 100
C     AIR PRESSURE NOT USED
   75 WRITE(LO,2002) STABNO,STABIL,IFLOWL,GAMMA,PERM
      NLINES=NLINES+1
      GO TO 100
C     -----------------------------------------------------------------
C     CUT AND COVER
   80 WRITE(LO,3004) NREACH,NTSEG,ISTA,ITENS,IHUNS,LSEGL,AR,ARTULT,IVTS,
     1 IVTR,IPH,ICTTS,ICTR,HOURS,DAYS
      IF(ISUPPT.EQ.5)  SPDLT=A(N,38)
      IF(ISUPPT.EQ.6) DSLURY=A(N,38)
      WRITE(LO,3005) STABNO,STABIL,IFLOWL,GAMMA,PERM,VL   ,BE,SIDESL,
     1DSLURY,SPDLT,BACKFL,OPEN
      NLINES=NLINES+1
      GO TO 100
C     -----------------------------------------------------------------
C     THIS SEGMENT IN SAME REACH AS PREVIOUS SEGMENT
   85 IF(LIST(4).EQ.1) GO TO 100
      WRITE(LO,2150)
      NLINES=NLINES+1
C     -----------------------------------------------------------------
      IF(NTSTYP.EQ.3) GO TO 95
C     ROCK OR SOFT GROUND TUNNEL
      WRITE(LO,3011) NTSEG,ISTA,ITENS,IHUNS,LSEGL,BFT,BE,BOB,AR,ARTULT,
     1TL,IVTS,IVTR,IFL,IPH,ICTTS
      IF(NTSTYP.EQ.1) GO TO 100
C     -----------------------------------------------------------------
C     SOFT GROUND TUNNEL
      IF(MSTAB.NE.1) GO TO 90
C     AIR LOCK NODAL POINTS
      NPLOCK=A(N,36)
      STA=CNP(NPLOCK,1)
      ISTA=STA/100.
      ISTA2=STA-ISTA*100
      ITENS=ISTA2/10.
      IHUNS=ISTA2-ITENS*10
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```
      IHUNS=IABS(IHUNS)
      WRITE(LO,3002) ISTA,ITENS,IHUNS,STABNO,STABIL,AIRPR,IFLOWL,GAMMA,
     1PERM
      NLINES=NLINES+1
      GO TO 100
C     AIR PRESSURE NOT USED
   90 WRITE(LO,2002) STABNO,STABIL,IFLOWL,GAMMA,PERM
      NLINES=NLINES+1
      GO TO 100
C     ------------------------------------------------------------------
C     CUT AND COVER
   95 WRITE(LO,3014) NTSEG,ISTA,ITENS,IHUNS,LSEGL,AR,ARTULT,IVTS,IVTR,
     1IPH,ICTTS
      IF(ISUPPT.EQ.5)  SPDLT=A(N,38)
      IF(ISUPPT.EQ.6) DSLURY=A(N,38)
      WRITE(LO,3015) STABNO,STABIL,IFLOWL,GAMMA,PERM,VL   ,BE,SIDESL,
     1DSLURY,SPDLT,BACKFL
      NLINES=NLINES+1
  100 IPR=NREACH
      IF(LIST(4).EQ.0) WRITE(LO,2222)
C     ------------------------------------------------------------------
C
C     OUTPUT CALCULATED SHAFT DATA
C
      IF(LIST(5).EQ.1) GO TO 300
      IPS=0
      ITYPE=2
      NLINES=40
      DO 200 N=1,NSS
      NLINES=NLINES+1
      IF(NLINES.LT.40) GO TO 102
      NLINES=0
      WRITE(LO,2000)
      WRITE(LO,2010)
  102 NSHAFT=B(N,1)
      NSSEG=B(N,2)
      BE=B(N,29)
      BOB=B(N,32)
      ARSULT=B(N,39)
      IPRML=SHAFT(NSHAFT,10)
      ICTSS=B(N,40)
      IADS=SHAFT(NSHAFT,9)*0.00003
      LSEGL=B(N,35)
      NPB=B(N,4)
      IELNPB=CNP(NPB,2)
      TL=B(N,11)*12.
       R=B(N,8)
      NPORT=SHAFT(NSHAFT,23)
      NSSTYP=B(N,15)
C     ------------------------------------------------------------------
C     EXCAVATED VOLUMES
      VROCK=0.0
      VSOIL=0.0
      V=B(N,38)
      IF(NSSTYP.EQ.1) VROCK=V
      IF(NSSTYP.EQ.2) VSOIL=V
      IVSR=VROCK
      IVSS=VSOIL
```

(Continued)

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C     ---------------------------------------------------------------
      IF(NSSTYP.EQ.1) GO TO 110
      GAMMA=B(N,18)
      PERM=ABS(B(N,23))
      IF(NSSTYP.EQ.3) GO TO 110
C     SOFT GROUND SHAFT
      AIRPR=B(N,27)
      IFLOWL=B(N,42)
      STABNO=B(N,24)
      MSTAB=B(N,25)
      IF(MSTAB.EQ.0) STABIL=TNONE
      IF(MSTAB.EQ.1) STABIL=AIRPRS
      IF(MSTAB.EQ.2) STABIL=DEWATR
      IF(MSTAB.EQ.3) STABIL=GRDINJ
C     ---------------------------------------------------------------
C     CHECK IF SEGMENT IN SAME SHAFT AS PREVIOUS SEGMENT
  110 IF(IPS.EQ.NSHAFT) GO TO 160
C     CONVERT STATIONING OF SHAFT TO INTEGER VALUES
      NPTS=SHAFT(NSHAFT,2)
      NPBS=SHAFT(NSHAFT,3)
      STA=CNP(NPBS,1)
      ISTA=STA/100.
      ISTA2=STA-ISTA*100
      ITENS=ISTA2/10.
      IHUNS=ISTA2-ITENS*10
      IHUNS=IABS(IHUNS)
      BFS=SHAFT(NSHAFT,7)
C     ---------------------------------------------------------------
C     CHECK FOR PORTAL
      IF(NPORT.EQ.0) GO TO 112
      WRITE(LO,2200) NSHAFT,ISTA,ITENS,IHUNS,IELNPB,IADS
      GO TO 200
C     ---------------------------------------------------------------
C     CHECK FOR DUMMY SHAFT
  112 ISHAPS=SHAFT(NSHAFT,16)
      IF(ISHAPS.GT.0) GO TO 115
      WRITE(LO,2100) NSHAFT,ISTA,ITENS,IHUNS,IELNPB,IADS
      GO TO 200
C     ---------------------------------------------------------------
C     CALCULATE CONSTRUCTION TIME FOR THE SHAFT    (CTS)
  115 NSEGS=SHAFT(NSHAFT,4)
      ICTS=0
      MEXP=0
      SETUSH=0.0
      SETUPM=0.0
      DO 120 I=1,NSEGS
      NN=N+I-1
      CTSS=B(NN,40)
      MEX=B(NN,7)
      NSSTYP=B(NN,15)
C     CHECK FOR SHAFT NOT CONSTRUCTED IN CUT AND COVER
      IF(NSSTYP.NE.3) CALL SETUP(MEX,MEXP,SETUSH,SETUPM,SETUPR,ITYPE)
  120 ICTS=ICTS+CTSS
      ICTS=ICTS+14.*SETUSH+28.*SETUPM
C     ---------------------------------------------------------------
  130 WRITE(LO,2222)
      NLINES=NLINES+1
      NSSTYP=B(N,15)
```

(Continued)

AD-A107 890 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/13
TUNNEL COST-ESTIMATING METHODS.(U)
OCT 81 R D BENNETT
UNCLASSIFIED WES/TR/GL-81-10 NL

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      HOURS=SHAFT(NSHAFT,17)
      DAYS=SHAFT(NSHAFT,18)
      IF(NSSTYP.EQ.3) GO TO 150
      WRITE(LO,2001) NSHAFT,NSSEG,ISTA,ITENS,IHUNS,IELNPB,LSEGL,BFS,BE,
     1BOB,AR,ARSULT,TL,IVSS,IVSR,IADS,ICTSS,ICTS,IPRML,HOURS,DAYS
      IF(NSSTYP.EQ.1) GO TO 200
C     ------------------------------------------------------------
C     SOFT GROUND SHAFT
      IF(MSTAB.NE.1) GO TO 140
C     COMPRESSED AIR USED
      WRITE(LO,2003) STABNO,STABIL,AIRPR,IFLOWL,GAMMA,PERM
      NLINES=NLINES+1
      GO TO 200
C     NO COMPRESSED AIR
  140 WRITE(LO,2002) STABNO,STABIL,IFLOWL,GAMMA,PERM
      NLINES=NLINES+1
      GO TO 200
C     ------------------------------------------------------------
C     CUT AND COVER
  150 WRITE(LO,2004) NSHAFT,NSSEG,ISTA,ITENS,IHUNS,IELNPB,LSEGL,BFS,TL,
     1IADS,HOURS,DAYS
      WRITE(LO,2005) GAMMA,PERM
      NLINES=NLINES+1
      GO TO 200
C     ------------------------------------------------------------
C     THIS SEGMENT IN SAME SHAFT AS PREVIOUS SEGMENT
  160 WRITE(LO,2150)
      NLINES=NLINES+1
      IF(NSSTYP.EQ.3) GO TO 170
      WRITE(LO,2011) NSSEG,IELNPB,LSEGL,BFS,BE,BOB,AR,ARSULT,TL,IVSS,
     1IVSR,ICTSS
      IF(NSSTYP.EQ.1) GO TO 200
C     ------------------------------------------------------------
C     SOFT GROUND SHAFT
      IF(MSTAB.NE.1) GO TO 165
C     COMPRESSED AIR USED
      WRITE(LO,2003) STABNO,STABIL,AIRPR,IFLOWL,GAMMA,PERM
      NLINES=NLINES+1
      GO TO 200
C     NO COMPRESSED AIR
  165 WRITE(LO,2002) STABNO,STABIL,IFLOWL,GAMMA,PERM
      NLINES=NLINES+1
      GO TO 200
C     ------------------------------------------------------------
C     CUT AND COVER
  170 WRITE(LO,2012) NSSEG,IELNPB,LSEGL,BFS,TL
      WRITE(LO,2005) GAMMA,PERM
      NLINES=NLINES+1
  200 IPS=NSHAFT
      WRITE(LO,2222)
C     ------------------------------------------------------------
  300 IF(IERROR.EQ.0) RETURN
C     FATAL ERRORS DETECTED WHICH MAY MAKE COST CALCULATIONS
C     MEANINGLESS. TERMINATE RUN AND GO TO NEXT SYSTEM DATA DECK
      WRITE(LO,1022)
      CALL NEXSET(LO,LI)
      RETURN
C     ------------------------------------------------------------
```

(Continued)

```
C
C     ************************************************************
 1020 FORMAT(/,35H FATAL ERROR, HAUL SLOPE IN SEGMENT,I5,9H IN REACH,
     1 I5,42H EXCEEDS 5 PERCENT --TOO STEEP FOR A TRAIN)
 1021 FORMAT(/,' FATAL ERROR, EXCAVATED DIMENSION IN SEGMENT',I5,' IN
     1REACH',I5,' IS TOO SMALL FOR A TRUCK,USE TRAIN OR CONVEYOR')
 1022 FORMAT(//,1X,100(1H*),/,10X,' EXECUTION HALTED AFTER SUBROUTINE
     1 CALCS DUE TO ERRORS    ',/,1X,100(1H*))
 1023 FORMAT(/,' FATAL ERROR, SLOPE OF SEGMENT',I5,' IN REACH',I5,
     1 ' EXCEEDS 26 PERCENT --TOO STEEP FOR MUCK TRANSPORT METHODS CON
     2SIDERED')
 1025 FORMAT(/,' FATAL ERROR, ALL TRUCK MUCK TRANSPORT IS SPECIFIED IN
     1 SEGMENT',I5,' IN REACH',I5,' IN WHICH COMPRESSED AIR IS USED')
 1030 FORMAT(/' **** REMINDER **** USE OF COMPRESSED AIR IN SEGMENT',
     1I5,' IN REACH',I5,' REQUIRES USE OF CONVEYOR-TRUCK TRANSPORT MET
     2HOD RATHER'/20X,'THAN INPUT METHOD')
 2000 FORMAT(1H1,42(1H*),'  C A L C U L A T E D   S H A F T   D A T A   ',
     146(1H*)//,' SHAFT SEG STATION  ELEV AT LENGTH *SHAFT DIMENSIONS* *
     2*ADVANCE RATES**  LINING *EXCAV VOLUME* SIZE OF  CONSTRUCTION RML-
     3 HOURS DAYS'/12X,'ALONG   BOTTOM   (FT)  FINISH EXCAV EXCAV    AVER
     4AGE UNIFORM  THICK   SOIL   ROCK   DISPOSAL  TIME (DAYS) MAX   PER
     5  PER'/12X,'TUNNEL  OF SEG             (FT)  (FT) W/O.B.   USED
     6          (IN)  (CY/FT)(CY/FT)   AREA    SEG  SHAFT  (CY/  DAY  WEEK
     7'/12X,'ALIGN.',36X,'(FT/DAY) (FT/DAY)',24X,'(ACRES)',16X,'HR)')
 2001 FORMAT(1X,I4,I5,I6,1H+,2I1,I7,I8,F7.2,2F6.2,2F8.1,F9.2,2I7,2I8,
     12I6,2F6.1)
 2002 FORMAT(21X,F5.1,2X,A6,6X,I9,1X,F11.1,E9.2)
 2003 FORMAT(21X,F5.1,2X,A6,F6.1,I9,1X,F11.1,E9.2)
 2004 FORMAT(1X,I4,I5,I6,1H+,2I1,I7,I8,F7.2,28X,F9.2,14X,I8,20X,2F6.1)
 2005 FORMAT(55X,F6.1,E9.2)
 2010 FORMAT(    33(2H--,2H  )/21X,'***STABILIZATION***  DEWATERING *SOIL
     1 PROPERTIES*'/21X,'NUMBER METHOD AIRPR  (GPM/WELL)   UNIT WT   PER
     2M'/35X,'(PSI)',16X,'(PCF) (CM/SEC)'//)
 2011 FORMAT(5X,I5,8X,2I8,F7.2,2F6.2,2F8.1,F9.2,2I7,8X,I8)
 2012 FORMAT(5X,I5,8X,2I8,F7.2,28X,F9.2)
 2150 FORMAT(1X)
 2100 FORMAT(1X,131(1H-)/1X,I4,5X,I6,1H+,2I1,I7,22X,' THIS SHAFT IS A
     1DUMMY',22X,I8)
 2200 FORMAT(1X,131(1H-)/1X,I4,5X,I6,1H+,2I1,I7,22X,' THIS SHAFT IS A
     1PORTAL',21X,I8)
 2222 FORMAT(1X,131(1H-))
 3000 FORMAT(1H1,41(1H*),'  C A L C U L A T E D   T U N N E L   D A T A  '
     1,45(1H*)//,' REACH SEG  STATION SLOPE  *TUNNEL DIMENSIONS* **ADVAN
     2CE RATES**  LINING *EXCAV VOLUME*  PUMP   PUMP  CONSTRUCTION RML-
     3HOURS DAYS'/12X,'AT LEFT LENGTH FINISH EXCAV EXCAV    AVERAGE UNIF
     4ORM  THICK   SOIL   ROCK    FLOW  HEIGHT  TIME (DAYS) MAX   PER  P
     5ER'/12X,'OF SEG   (FT)   (FT)  (FT)  W/O.B.    USED             (I
     6N)  (CY/FT)(CY/FT)  RATE    (FT)   SEG  REACH  (CY/  DAY  WEEK'/40X
     7,'(FT)    (FT/DAY) (FT/DAY)',25X,'(GPM)',22X,'HR)')
 3001 FORMAT(1X,I4,I5,I6,1H+,2I1,I6,2F7.2,F6.2,F8.1,F9.1,F9.2,2I7,I8,I7,
     13I6,2F6.1)
 3002 FORMAT(11X,I5,1H+,2I1,F7.1,2X,A6,F6.1,I9,1X,F11.1,E9.2)
 3004 FORMAT(1X,I4,I5,I6,1H+,2I1,I6,20X,F8.1,F9.1,9X,2I7,8X,I7,2I6,6X,
     12F6.1)
 3005 FORMAT(21X,F5.1,2X,A6,6X,I9,1X,F11.1,E9.2,F8.1,F8.2,F6.2,2F7.1,
     1F8.0,T114,' ',F8.0,T122,' ')
 3010 FORMAT(    33(2H--,2H  )/12X,'AIRLOCK  ***STABILIZATION***  DEWATER
     1ING *SOIL PROPERTIES*  CONCRETE *CUT AND COVER SEGMENT PROPERTIES*
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     2  REACH'/12X,'STATION  NUMBER METHOD AIRPR  (GPM/WELL)   UNIT WT
     3 PERM     BOX      BASE SIDE *SUPORT LENGTH*  BACKFL  OPEN'/12X,
     4'SG TUN',17X,'(PSI) SUMP(GPM/FT)    (PCF)  (CM/SEC)  VOLUME  WIDTH
     5SLOPE SLURRY  DECKED  VOLUME  LENGTH'/72X,'(CY/FT)    (FT)         W
     6ALL  SOLDIER (CY/FT)    (FT)'//)
 3011 FORMAT(5X,I5,I6,1H+,2I1,I6,2F7.2,F6.2,F8.1,F9.1,F9.2,2I7,I8,I7,I6)
 3014 FORMAT(5X,I5,I6,1H+,2I1,I6,20X,F8.1,F9.1,9X,2I7,8X,I7,I6)
 3016 FORMAT(21X,F6.1,2X,A6,6X,I9,1X,F11.1,E9.2,F8.1,F8.2,F6.2,2F7.1,
     1F8.0,T114,' ')
C     ***************************************************************
C
C
      RETURN
      END
      SUBROUTINE SETUP(MEX,MEXP,SETUSH,SETUPM,SETUPR,ITYPE)
C     ---------------------------------------------------------------
C     THIS SUBROUTINE COMPUTES THE NUMBER OF SETUP FOR SHIELD, MOLE,
C     AND RIPPER EXCAVATION
C     ---------------------------------------------------------------
      IF(ITYPE.EQ.2) GO TO 500
C     TUNNEL
      IF(MEX.LE.1.OR.MEX.GE.)1`/~E10 600
      IF(MEX.LT.3) GO TO 100
C     SHIELD SETUP
      IF(SETUSH.GE.1..AND.(MEXP.LT.3.OR.MEXP.GE.6)) SETUSH=SETUSH+0.25
      IF(SETUSH.LT.1.) SETUSH=1.
  100 IF(MEX.GT.3) GO TO 400
C     ---------------------------------------------------------------
C     MOLE SETUP
      IF (SETUPM.GE.1.) GO TO 150
C     FIRST MOLE SETUP
      SETUPM=1.
      GO TO 600
  150 IF(MEXP.EQ.2.OR.MEXP.EQ.3) GO TO 200
C     RESETUP
      SETUPM=SETUPM+0.25
      GO TO 600
C     CHANGE CUTTER
  200 IF(MEXP.NE.MEX) SETUPM=SETUPM+0.125
      GO TO 600
C     RIPPER SETUP
  400 IF(MEX.EQ.4) GO TO 600
C     RESETUP
      IF(MEXP.NE.5.AND.SETUPR.GE.1.) SETUPR=SETUPR+0.25
      IF(SETUPR.LT.1.) SETUPR=1.
      GO TO 600
C     ---------------------------------------------------------------
C     SHAFT
  500 IF(MEX.LT.2) GO TO 600
C     SHIELD SETUP
      IF(MEX.GE.3.AND.SETUSH.LT.1.) SETUSH=1.
      IF(MEX.EQ.4) GO TO 600
      IF(SETUPM.LT.1.) GO TO 550
C     CHANGE CUTTER
      IF(MEX.EQ.2.AND.MEXP.EQ.3) SETUPM=SETUPM+0.125
      GO TO 600
C     FIRST SETUP
  550 SETUPM=1.
```

(Continued)

```
  600 MEXP=MEX
      RETURN
      END
      SUBROUTINE COSTTU(A,CNP,SHAFT,TRDATA,CUMSL,NTSMAX,NPMAX,NSMAX,
     1NTRMAX,NSSMAX)
C      COSTTU COLLECTS ALL OF THE TUNNEL COSTS AND OUTPUTS THEM
C     -----------------------------------------------------------------
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON/G/ TUNLC,TUNEC,TUNMC,TUNTC
      DIMENSION IL(12),IE(12),IM(12),CF(3)
      DIMENSION  A(NTSMAX,68),           CNP(NPMAX,2),SHAFT(NSMAX,23),
     1 TRDATA(NTRMAX,23),CUMSL(NPMAX)
C     -----------------------------------------------------------------
      INTEGER  SLCPF,SECPF,SMCPF,TLC,TEC,TMC
      INTEGER TCES,TCE,TCML,TCMT,TCMH,TCMD,TCTS,TCL,TCFW,
     1         TCG,TCP,TCAC,TSCPF,  TSC
      INTEGER RCL,RCE,RCM,RCT
      INTEGER TUNLC,TUNEC,TUNMC,TUNTC
C     -----------------------------------------------------------------
C     CALCULATE TUNNEL COSTS A REACH AT A TIME
      ITYPE=1
C
      TUNLC=0
      TUNEC=0
      TUNMC=0
      TUNTC=0
C
      DO  950  NREACH=1,NTRMAX
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 950
      NSHAFT=TRDATA(NREACH,1)
      BF=TRDATA(NREACH,2)
      ISHAPE=TRDATA(NREACH,3)
      MTM=TRDATA(NREACH,4)
      NRSEG1=TRDATA(NREACH,5)
      NSEGS=TRDATA(NREACH,6)
      RMLMAX=TRDATA(NREACH,7)
      HOURS =TRDATA(NREACH,8)
      DAYS  =TRDATA(NREACH,9)
      SETUSH=TRDATA(NREACH,10)
      SETUPM=TRDATA(NREACH,11)
      SETUPR=TRDATA(NREACH,12)
      DTCA  =TRDATA(NREACH,14)
      DTC  =TRDATA(NREACH,15)
      IF(ISHAPE.EQ.1) SFA=0.785
      IF(ISHAPE.EQ.1) SFP=3.14
      IF(ISHAPE.EQ.2) SFA=0.893
      IF(ISHAPE.EQ.2) SFP=3.57
      IF(ISHAPE.EQ.3) SFA=0.425
      IF(ISHAPE.EQ.3) SFP=2.66
C
      NBOX  =TRDATA(NREACH,10)
      BFBWDT  =TRDATA(NREACH,11)
      BFBHT  =TRDATA(NREACH,12)
      IBOX2  =TRDATA(NREACH,13)
      TIMEDW=TRDATA(NREACH,14)
      OPEN  =TRDATA(NREACH,16)
```

(Continued)

```
      VDS =TRDATA(NREACH,21)
      VBACEX=TRDATA(NREACH,22)
      VBACDS=TRDATA(NREACH,23)
C
      NPBS=SHAFT(NSHAFT,3)
      DDS=SHAFT(NSHAFT,5)
      CDS=SHAFT(NSHAFT,6)
      HH=SHAFT(NSHAFT,8)
      NSEGSA=IABS(NSEGS)
C     ---------------------------------------------------------------
C     DETERMINE NUMBER OF SHIFTS IN A WORK DAY
      SHIFTS=1.
      IF(HOURS.GE.12.) SHIFTS=2.
      IF(HOURS.GE.21.) SHIFTS=3.
C     CALCULATE COST FACTORS FOR LENGTH OF WORK WEEK
      IF(HOURS/SHIFTS.LE.8.) CFLWWK=(6.08+0.192*(DAYS-4.)**2
     1 +0.384*SHIFTS)*SHIFTS/HOURS
      IF(HOURS/SHIFTS.GT.8.) CFLWWK=(0.76+0.024*(DAYS-4.)**2
     1 +0.048*SHIFTS)*(1.5-4.*SHIFTS/HOURS)
      CFEWWK=(3.75+30./HOURS)/DAYS
C     ---------------------------------------------------------------
      ALOCK=1.0
      CLIND=0.
      UCMCP=0.
      IF(ISHAPE.EQ.0.OR.DTCA.EQ.0.) GO TO 5
C     CALCULATE COST OF INSTALLATION OF CONVEYOR IN FREE AIR FOR
C     CONVEYOR+TRUCK TRANSPORT, AND COST OF COMPRESSED AIR PIPING
      CALL CVINFA(A,CNP,CUMSL,HH,NPBS,NSEGS,RMLMAX,DTCA,NRSEG1,
     1 CLIND,UCMCP,NTSMAX,NPMAX)
C     ---------------------------------------------------------------
C     CALCULATE NUMBER OF AIR LOCK LOCATIONS AND LENGTH OF LOCK
      CALL LOCKLT(A,NSEGS,RMLMAX,MTM,ALOCK,ALOCKL,NTSMAX,NRSEG1)
C     ---------------------------------------------------------------
    5 RL=0.0
      DO 10 IJ=1,NSEGSA
      IF(NSEGS.GT.0) I=NRSEG1+IJ-1
      IF(NSEGS.LT.0) I=NRSEG1-IJ+1
      TSEGL=A(I,45)
   10 RL=RL+TSEGL
C     ---------------------------------------------------------------
      RCL=0.
      RCE=0.
      RCM=0.
      RCT=0.
      NLINES=60
C
C     CALCULATE TUNNEL COSTS FOR EACH SEGMENT
C
C
      DO 900 IS=1,NSEGSA
C     I=SEQUENCE NUMBER OF TUNNEL SEGMENT
      I=NRSEG1+IS-1
      NPS=A(I,17)
      IF(NSEGS.GT.0) GO TO 110
      I=NRSEG1-IS+1
      NPS=A(I,18)
  110 NPL    =A(I,2)
      NPR    =A(I,3)
```

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```
      ELNPL =CNP(NPL,2)
      ELNPR =CNP(NPR,2)
      ELAVG =0.5*(ELNPL+ELNPR)
      RS=A(I,5)
      RQD=A(I,6)
      MEX=A(I,7)
      AR=A(I,8)
      GI=A(I,9)
C     THE VARIABLE  FOR LINING TYPE  IS CALLED L1(ONE)N1(ONE)NG IN THIS
C                                              --      --     --
C     SUBROUTINE TO AVOID COMPUTER CONFUSION WITH THE CALL TO SUB LINING
C     WHICH COMPUTES LINING COSTS
      LINING=A(I,10)
      TL     =A(I,11)
      TSEG   =A(I,11)
      NOFORM=A(I,13)
      ELWATR=A(I,14)
      LINWT =A(I,15)
      NTSTYP=A(I,16)
      IF(NTSTYP.EQ.1) GO TO 115
      NPLS   =A(I,17)
      NPRS   =A(I,18)
C     CALCULATE AVERAGE SURFACE ELEVATION
      ELNPLS=CNP(NPLS,2)
      ELNPRS=CNP(NPRS,2)
      ELSURF=0.5*(ELNPLS+ELNPRS)
C     DEPTH OF TUNNEL
      DTUN=ELSURF-ELAVG
C     CALCULATE DEPTH OF ROCK SURFACE
      ELROCK=A(I,27)
      DROCK=ELSURF-ELROCK
C
  115 ELBOTM=ELAVG-0.5*BE
      IF(ISHAPE.EQ.3) ELBOTM=ELAVG-0.25*BE
C
      D10    =A(I,19)
      PHI    =A(I,20)
      PERM=A(I,25)
      ISUPPT=A(I,26)
      IBRACE=A(I,28)
      IDECK=A(I,29)
      STABNO=A(I,30)
      MSTAB=A(I,31)
      AIRPR=A(I,33)
      CAVT   =A(I,35)
      QT     =A(I,37)
      Q      =A(I,38)
      BE     =A(I,39)
      BE40   =A(I,40)
      BE60   =A(I,41)
```

(Continued)

```
      BOB   =A(I,42)
      BOB40 =A(I,43)
      BOB60 =A(I,44)
C
      TSEQL =A(I,45)
      DM    =A(I,46)
      HSLOPE=A(I,47)
      RML   =A(I,48)
      V     =A(I,51)
C
      TOTBOX=A(I,43)
      DTRNCH=A(I,52)
      SIDESL=A(I,53)
      VBOX  =A(I,54)
      VL    =A(I,55)
      FORMAR=A(I,56)
C
      PH    =A(I,57)
      PIPL  =A(I,58)
      FLOW  =A(I,59)
      GIR   =A(I,60)
      FLOWL =A(I,61)
C
      WEB   =A(I,62)
      TPLATE=A(I,62)
      WTWALE=A(I,63)
      WTSTRT=A(I,64)
      WTANCH=A(I,65)
      WTSP  =A(I,66)
      WTSPD =A(I,67)
C
      WELLS =A(I,68)
      SPDLT =A(I,38)
      DSLURY=A(I,38)
      PSOIL =A(I,63)
      PWATER=A(I,64)
      PTOTAL=A(I,65)
      IWATER=A(I,23)
C     ------------------------------------------------------------------
C     LABOR COST FACTOR IN COMPRESSED AIR
      CFLCA=AIRPR**2/400.+1.5
      IF(NTSTYP.NE.2.OR.AIRPR.LE.0.) CFLCA=1.
C     COST FACTOR FOR TRAVEL TIME TO THE FACE
      Y=0.3*SHIFTS*(0.76+0.024*(DAYS-4.)**2+0.048*SHIFTS)
      IF(HOURS/SHIFTS.LT.8.) Y=Y*5.*(HOURS/SHIFTS+0.2*DM-8.)/DM
      IF(Y.LT.0.) Y=0.
      IF(NTSTYP.EQ.3) Y=0.
C
      CLES=0.
      CEES=0.
      CMES=0.
      CLAC=0.
      CEAC=0.
      CMAC=0.
      IF(NTSTYP.EQ.3) GO TO 750
      IF(MSTAB.NE.1) GO TO 750
      IF(IS.NE.1) GO TO 700
      DLOCK=0.
```

(Continued)

```
      NPLOCK= ABS(A(I,36))
      DTHLOK=HH
      PUMPLT=DTHLOK+DM*5280.
      GO TO 750
C     CALCULATE LENGTH OF PIPING FOR COMPRESSED AIR
  700 IF( ABS(A(I,36)).EQ.NPLOCK) GO TO 720
      NPLOCK= ABS(A(I,36))
      DTHLOK=CNP(NPS,2)-CNP(NPLOCK,2)
      DLOCK=ABS(CUMSL(NPLOCK)-CUMSL(NPBS))
  720 PUMPLT=DM*5280.-DLOCK+DTHLOK
      IF(DLOCK.GT.0.001) HSFA=(CNP(NPBS,2)-CNP(NPLOCK,2))/DLOCK
      HSCA=(CNP(NPLOCK,2)-ELAVG)/(DM*5280.-DLOCK)
C     -----------------------------------------------------------------
C     CALCULATE SETUP COST FOR TUNNEL SEGMENT I
  750 CALL CSETUP(A,B,NSEGS,NRSEG1,BE,HH,ITYPE,I ,SETUSH,SETUPM,SETUPR,
     1 CLES,CEES,CMES,CFLWWK,CFEWWK,NTSTYP,DSES,DMES,DRES,NTSMAX,NSSMAX)
C     -----------------------------------------------------------------
C     CALCULATE COST OF EXCAVATION IN TUNNEL SEGMENT I
      CALL COEX(CLE,CEE,CME,ITYPE,MEX,AR,BE,RS,ISHAPE,SFA,SFP,
     1          PSOIL,STABNO,DTRNCH,DROCK,SIDESL,VBOX,VSOIL,VROCK,PHI,
     2          DCENT,HOURS,Y,DM,MSTAB,CFLCA,CFLWWK,CFEWWK,NTSTYP)
C     -----------------------------------------------------------------
C     CALCULATE COST OF MUCK LOADING IN TUNNEL SEGMENT I
      CALL CMUKLD(CLML,CEML,CMML,ITYPE,MEX,AR,DM,V,Y,RML,RMLMAX,
     1              MSTAB,CFLCA,CFLWWK,CFEWWK,HOURS)
C     -----------------------------------------------------------------
C     CALCULATE MUCK TRANSPORTATION AND HOISTING COSTS FOR
C     TUNNEL SEGMENT I
      CALL CMTAH(CLMT,CEMT,CMMT,CLMH,CEMH,CMMH,ITYPE,MTM,DM,AR,
     1HSFA,V,HH,LINING,RML,RMLMAX,HSLOPE,BE,ISHAPE,RL,UCLT,UCET,Y,UCLMH,
     2HSCA,UCEMH,MSTAB,DLOCK,CLIND,HOURS,OPEN,DCENT,VBACEX,VBACDS,VBOX,
     3  VSOIL,VROCK,TOTBOX,CFLWWK,CFEWWK,CFLCA,DDS,NTSTYP,DTRNCH,DROCK)
C     -----------------------------------------------------------------
C     CALCULATE MUCK DISPOSAL COST FOR TUNNEL SEGMENT I
      CALL CMUKDP(CLMD,CEMD,CMMD,AR,V,CDS,DDS,VDS,NTSTYP,HOURS,
     1          CFLWWK,CFEWWK,ITYPE)
C     -----------------------------------------------------------------
C     CALCULATE COST OF TUNNEL SUPPORTS FOR TUNNEL SEGMENT I
      IF(LINING.EQ.4.AND.NTSTYP.EQ.1)GO TO 1900
      IF(LINING.NE.4.OR.NTSTYP.NE.1)GO TO 2000
 1900 CALL ROCK(CLTS,CETS,CMTS,RQD,MEX,ISHAPE,BE,AR,RS,BE40,BE60,
     1ITYPE,Y,NSTYP,BF,ISUPPT,TPLATE,TSEG,PSOIL,WEB,PTOTAL,
     2BOB,LINWT,MSTAB,CFLCA,HOURS,CFLWWK,CFEWWK,SFA,LINING,DM,
     3CLL,CEL,CML,CLFW,CEFW,CMFW)
      GO TO 2500
 2000 CONTINUE
      CALL CTSUP(CLTS,CETS,CMTS,RQD,MEX,ISHAPE,BE,AR,RS,BE40,BE60,ITYPE,
     1    Y,DM,NTSTYP,BF,ISUPPT,TPLATE,TSEG,PSOIL,WEB,PTOTAL,BOB,LINWT,
     2    MSTAB,CFLCA,HOURS,CFLWWK,CFEWWK,DSLURY,DTRNCH,IDECK,DROCK,
     3    WTSTRT,WTWALE,SPDLT,WTSPD,WTSP,WTANCH,TOTBOX,IBRACE,SFA)
C     -----------------------------------------------------------------
C     CALCULATE COST OF LINING AND FORMWORK IN TUNNEL SEGMENT I
      CALL LINING1(CLL,CEL,CML,CLFW,CEFW,CMFW,ITYPE,LINING,RQD,MEX,
     1WEB,TL,BOB,BOB40,BF,Y,DM,BOB60,ISHAPE,BE,UCLT,UCET,MTM,
     2UCLMH,UCEMH,SFA,NOFORM,AR,NTSTYP,PSOIL,PWATER,VL,SFP,
     3FORMAR,HOURS,CFLCA,CFLWWK,CFEWWK)
 2500 CONTINUE
C     -----------------------------------------------------------------
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(Continued)

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C     CALCULATE GROUTING COSTS FOR TUNNEL SEGMENT I
      CALL CGROUT(CLG,CEG,CMG,ITYPE,GI,ISHAPE,BE,AR,RS,NTSTYP,MSTAB,
     1          DTUN,HH,HOURS,CFLWWK,CFEWWK,SSEGL,PERM,SFP,DTG,TIMEG)
C     ------------------------------------------------------------------
C     CALCULATE COST OF PUMPING FOR TUNNEL SEGMENT I
      CALL CPUMP(CLP,CEP,CMP,NTSTYP,FLOW,PH,PIPL,AR,ITYPE,
     1          ELSURF,ELBOTM,DAYS,LINING,PUMPTM,MEX,DTRNCH,DROCK,FLOWL,
     2          WELLS,RL,TIMEDW,ISUPPT,ELWATR,ELNPB,IWATER,CFLWWK,CFEWWK)
C     ------------------------------------------------------------------
C     CALCULATE COST OF AIR CONDITIONING AND COMPRESSED AIR FOR TUNNEL
C     SEGMENT I
      CALL CAIRC(CLAC,CEAC,CMAC,Q,QT,BE,BF,AR,HOURS,NTSTYP,MSTAB,ITYPE,
     1          AIRPR,     SFA,ISHAPE,HH,CAUT,ALOCK,DTC,DTCA,PUMPLT,DM,
     2           ALOCKL,UCMCP,CFLWWK,CFEWWK,DAYS,Y,PERM)
C     ------------------------------------------------------------------
C
C
C     ------------------------------------------------------------------
      IF(LIST(6).EQ.1) GO TO 810
      IF(NLINES+10.LT.60) GO TO 810
      WRITE(LO,1000)
      NLINES=6
C     ------------------------------------------------------------------
C     CALCULATE COST FACTORS
  810 POP=(1.+0.01*OM)*(1.+0.01*PM)
C     CF(1),CF(2) AND CF(3) ARE COMPOSITE COST FACTORS FOR L, E, AND M.
      CFL=SHAFT(NSHAFT,12)
      CFE=SHAFT(NSHAFT,13)
      CFM=SHAFT(NSHAFT,14)
      RCF=SHAFT(NSHAFT,15)
      CF(1)=POP*CFL*RCF
      CF(2)=POP*CFE*RCF
      CF(3)=POP*CFM*RCF
C     ------------------------------------------------------------------
C     MULTIPLY BY COMPOSITE COST FACTORS AND THEN OBTAIN SEGMENT
C     COSTS PER FOOT TO THE NEAREST DOLLAR
      IL( 1)=CLES*CF(1)+.5
      IE( 1)=CEES*CF(2)+.5
      IM( 1)=CMES*CF(3)+.5
      IL( 2)=CLE *CF(1)+.5
      IE( 2)=CEE *CF(2)+.5
      IM( 2)=CME *CF(3)+.5
      IL( 3)=CLML*CF(1)+.5
      IE( 3)=CEML*CF(2)+.5
      IM( 3)=CMML*CF(3)+.5
      IL( 4)=CLMT*CF(1)+.5
      IE( 4)=CEMT*CF(2)+.5
      IM( 4)=CMMT*CF(3)+.5
      IL( 5)=CLMH*CF(1)+.5
      IE( 5)=CEMH*CF(2)+.5
      IM( 5)=CMMH*CF(3)+.5
      IL( 6)=CLMD*CF(1)+.5
      IE( 6)=CEMD*CF(2)+.5
      IM( 6)=CMMD*CF(3)+.5
      IL( 7)=CLTS*CF(1)+.5
      IE( 7)=CETS*CF(2)+.5
      IM( 7)=CMTS*CF(3)+.5
      IL( 8)=CLL *CF(1)+.5
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(Continued)

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      IE( 8)=CEL *CF(2)+.5
      IM( 8)=CML *CF(3)+.5
      IL( 9)=CLFU*CF(1)+.5
      IE( 9)=CEFU*CF(2)+.5
      IM( 9)=CMFU*CF(3)+.5
      IL(10)=CLG *CF(1)+.5
      IE(10)=CEG *CF(2)+.5
      IM(10)=CMG *CF(3)+.5
      IL(11)=CLP *CF(1)+.5
      IE(11)=CEP *CF(2)+.5
      IM(11)=CMP *CF(3)+.5
      IL(12)=CLAC*CF(1)+.5
      IE(12)=CEAC*CF(2)+.5
      IM(12)=CMAC*CF(3)+.5
C     ----------------------------------------------------------------
C     CALCULATE SEGMENT COST/FOOT FOR LABOR, EQUIPMENT AND MATERIALS
      SLCPF=0
      SECPF=0
      SMCPF=0
      DO 815 LL=1,12
      SLCPF=SLCPF+IL(LL)
      SECPF=SECPF+IE(LL)
  815 SMCPF=SMCPF+IM(LL)
      TSCPF=SLCPF+SECPF+SMCPF
C     ----------------------------------------------------------------
C     CALCULATE TOTAL SEGMENT COST/FOOT FOR EACH COST COMPONENT
      TCES = IE( 1)+IM( 1)+IL( 1)
      TCE  = IE( 2)+IM( 2)+IL( 2)
      TCML = IE( 3)+IM( 3)+IL( 3)
      TCMT = IE( 4)+IM( 4)+IL( 4)
      TCMH = IE( 5)+IM( 5)+IL( 5)
      TCMD = IE( 6)+IM( 6)+IL( 6)
      TCTS = IE( 7)+IM( 7)+IL( 7)
      TCL  = IE( 8)+IM( 8)+IL( 8)
      TCFW = IE( 9)+IM( 9)+IL( 9)
      TCG  = IE(10)+IM(10)+IL(10)
      TCP  = IE(11)+IM(11)+IL(11)
      TCAC = IE(12)+IM(12)+IL(12)
C     ----------------------------------------------------------------
C     CALCULATE TOTAL SEGMENT COSTS IN THOUSANDS OF DOLLARS
      TLC = SLCPF*TSEGL/1000.
      TEC = SECPF*TSEGL/1000.
      TMC = SMCPF*TSEGL/1000.
      TSC = TLC+TEC+TMC
C     ----------------------------------------------------------------
      IF(LIST(6).EQ.1) GO TO 840
C     WRITE OUT THE SEGMENT COSTS FOR LABOR, EQUIP, MAT, AND TOTAL
      ITSEGL=TSEGL
      NTSEG=A(I,1)
      WRITE(LO,1001) NREACH,NTSEG,(IL(JJJ),JJJ=1,12),SLCPF,TLC
      WRITE(LO,1002)              (IE(JJJ),JJJ=1,12),SECPF,TEC
      WRITE(LO,1003)              (IM(JJJ),JJJ=1,12),SMCPF,TMC
      WRITE(LO,1004) TCES,TCE,TCML,TCMT,TCMH,TCMD,TCTS,TCL,TCFW,
     1TCG,TCP,TCAC,TSCPF,ITSEGL,  TSC
C
      NLINES=NLINES+5
C
C     ACCUMULATE TUNNEL SEGMENT COSTS INTO COST OF REACH
```

```
  840 RCL=RCL+TLC
      RCE=RCE+TEC
      RCM=RCM+TMC
      RCT=RCL+RCE+RCM
C     END OF COSTS ON A SEGMENT BASIS
  900 CONTINUE
C     ---------------------------------------------------------------
C     LIST OUT REACH COSTS
  850 IF(LIST(6).EQ.1) GO TO 860
      WRITE(LO,1007) SHAFT(NSHAFT,12),RCL, SHAFT(NSHAFT,15),
     1 SHAFT(NSHAFT,13),RCE,SHAFT(NSHAFT,14),RCM,CFLWWK,RCT,CFEWWK
      NLINES=NLINES+7
C
C     ---------------------------------------------------------------
C     ACCUMULATE COSTS OF ALL REACHES
  860 TUNLC=TUNLC+RCL
      TUNEC=TUNEC+RCE
      TUNMC=TUNMC+RCM
      TUNTC=TUNTC+RCT
C
      TRDATA(NREACH,17)=RCL
      TRDATA(NREACH,18)=RCE
      TRDATA(NREACH,19)=RCM
      TRDATA(NREACH,20)=RCT
C     END OF COSTS ON A REACH BASIS
  950 CONTINUE
      RETURN
C
C     ---------------------------------------------------------------
C     ---------------------------------------------------------------
 1000 FORMAT(1H1,47(1H*),27H  T U N N E L   C O S T S  ,46(1H*)//
     1120H REACH SEG  **************** COST IN DOLLARS PER FOOT OF TUNNE
     2L ******************** SEG   SEGMENT    SEGMENT                /
     3120H  NO   NO    EXC    EXC  MUCK  MUCK  MUCK  MUCK SUP-   LIN-
     4LIN GROUT PUMP-  AIR-  COST  LENGTH       COST                 /
     5120H             SETUP        LOAD  TRAN HOIST  DISP PORTS   ING  F
     6ORM          ING  COND ($/FT)  (FEET)    ($1000)
     7  /,1X,119(1H-))
 1001 FORMAT(/1X,I3,I5,2H L,13I6,8X,I12)
 1002 FORMAT(9X,      2H E,13I6,8X,I12)
 1003 FORMAT(9X,      2H M,13I6,8X,I12)
 1004 FORMAT(9X,      2H T,13I6,I8,I12)
 1007 FORMAT(1X,119(1H-),//, 9X, 14HREGIONAL  COST,6X,10HCOST INDEX,10X,
     1 10H -- LABOR   ,F5.2,5X,31HTOTAL REACH LABOR COST ........,I9/
     2 9X,9HFACTOR    ,F5.2,26X,10HEQUIPMENT ,F5.2,5X,
     3                          31HTOTAL REACH EQUIPMENT COST ....,I9/
     4 49X,10HMATERIALS ,F5.2,5X,31HTOTAL REACH MATERIALS COST ....,I9/
     5 43X,16HLABOR WORK WEEK ,F5.2,5X,
     6 31HTOTAL REACH COST ..............,I9/
     7 43X,16HEQUIP WORK WEEK ,F5.2)
C     ---------------------------------------------------------------
C
      END
      SUBROUTINE COSTSF(B,CNP,SHAFT,TRDATA,NSSMAX,NPMAX,NSMAX,NTRMAX,
     1NTSMAX)
C     ---------------------------------------------------------------
```

(Continued)

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C     -------------------------------------------------------------------
C     COSTSF COLLECTS ALL OF THE SHAFT COSTS AND OUTPUTS THEM
C     -------------------------------------------------------------------
C     -------------------------------------------------------------------
      DIMENSION IL(11),IE(11),IM(11),CF(3)
      COMMON /A/ LO,LI,PM,OM,LIST(40),TITLE(160),STABEG,ITYPE
      COMMON/Q/ TUNLC,TUNEC,TUNMC,TUNTC
      DIMENSION B(NSSMAX,43),CNP(NPMAX,2),SHAFT(NSMAX,23),TRDATA(NTRMAX,
     1   23)
C     -------------------------------------------------------------------
      INTEGER  SLCPF,SECPF,SMCPF,TLC,TEC,TMC
      INTEGER TCES,TCE,TCML,      TCMH,TCMD,TCTS,TCL,TCFW,TCP,TCAC,
     1        TCG,TSCPF,TSC
      INTEGER SCL,SCE,SCM,SCT
      INTEGER TUNLC,TUNEC,TUNMC,TUNTC
      INTEGER SFTTLC,SFTTEC,SFTTMC,SFTTC
      INTEGER TLABOR,TEQUIP,TMATER,TCOST
      INTEGER RCL,RCE,RCM,RCT
C     -------------------------------------------------------------------
C     CALCULATE COSTS A SHAFT AT A TIME
      Y=0.0
      ITYPE=2
C
C
      SFTTLC=0
      SFTTEC=0
      SFTTMC=0
      SFTTC=0
      DO  950  NSHAFT=1,NSMAX
      IF(SHAFT(NSHAFT,1).LT.-10.E29) GO TO 950
      BF=SHAFT(NSHAFT,7)
      NSSEG1=SHAFT(NSHAFT,1)
      NSEGS=SHAFT(NSHAFT,4)
      RMLMAX=SHAFT(NSHAFT,10)
      DDS=SHAFT(NSHAFT,5)
      CDS=SHAFT(NSHAFT,6)
C
      ISHAPS=SHAFT(NSHAFT,16)
      HOURS =SHAFT(NSHAFT,17)
      DAYS  =SHAFT(NSHAFT,18)
      NPORT =SHAFT(NSHAFT,23)
      SFA=0.785
      SFP=3.14
      IF(ISHAPS.EQ.2) SFA=1.0
      IF(ISHAPS.EQ.2) SFP=4.0
C     DETERMINE NUMBER OF SHIFTS PER WORK DAY
      SHIFTS=1.
      IF(HOURS.GE.12.) SHIFTS=2.
      IF(HOURS.GE.21.) SHIFTS=3.
C     CALCULATE COST FACTOR FOR LENGTH OF WORK WEEK
      IF(HOURS/SHIFTS.LE.8.) CFLWWK=(6.08+0.192*(DAYS-4.)**2
     1                   +0.384*SHIFTS)*SHIFTS/HOURS
      IF(HOURS/SHIFTS.GT.8.) CFLWWK=(0.76+0.024*(DAYS-4.)**2
     1                   +0.048*SHIFTS)*(1.5-4.*SHIFTS/HOURS)
      CFEWWK=(3.75+30./HOURS)/DAYS
C     -------------------------------------------------------------------
C     CALCULATE LENGTH OF SEGMENTS REQUIRE GROUTING AND PUMPING
      DTG=0.
```

(Continued)

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      DTP=0.
      DO 10 NN=1,NSEGS
      II=NSSEG1+NN-1
      MSTAB=B(II,25)
      SSEGL =B(II,35)
      HH    =B(II,36)
      FLOWL=B(II,42)
      IF(FLOWL.GT.0.) DTP=DTP+SSEGL
      IF(MSTAB.NE.3.OR.HH.GT.200.) GO TO 10
      DTG=DTG+SSEGL
      TIMEG=0.33+(HH+0.5*SSEGL)/20.
   10 CONTINUE
C     ---------------------------------------------------------------
      SCL=0.
      SCE=0.
      SCM=0.
      SCT=0.
      NLINES=60
C
C     CALCULATE SHAFT COSTS FOR EACH SEGMENT
C
C
      DO 900 ISS=1,NSEGS
C     I=SEQUENCE NUMBER OF SHAFT SEGMENT
      I=NSSEG1+ISS-1
C     CHECK FOR A PORTAL OR A DUMMY SHAFT
      IF(NPORT.EQ.0.AND.ISHAPS.NE.0) GO TO 67
C     THIS SHAFT IS A PORTAL OR A DUMMY SHAFT
      IF(LIST(7).EQ.0) WRITE(LO,3005) NSHAFT
      GO TO 860
   67 NPB=B(I,4)
      ELNPB=CNP(NPB,2)
      RS=B(I,5)
      RQD=B(I,6)
      MEX=B(I,7)
      AR=B(I,8)
      GI=B(I,9)
C     THE VARIABLE  FOR LINING TYPE  IS CALLED L1(ONE)N1(ONE)NG IN THIS
C                                                  --     --     --
C     SUBROUTINE TO AVOID COMPUTER CONFUSION WITH THE CALL TO SUB LINING
C     WHICH COMPUTES LINING COSTS
      L1N1NG=B(I,10)
      TL=B(I,11)
      TSEG  =B(I,11)
      NOFORM=B(I,12)
      ELWATR=B(I,13)
      LINWT =B(I,14)
      NSSTYP=B(I,15)
      D10   =B(I,16)
C
      PHI   =B(I,19)
      ELIMP =B(I,20)
      IWATER=B(I,21)
      ISUPPT=B(I,22)
      PERM=B(I,23)
      STABNO=B(I,24)
      MSTAB =B(I,25)
      AIRPR =B(I,27)
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(Continued)

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C
      BE     =B(I,29)
      BE40   =B(I,30)
      BE60   =B(I,31)
      BOB    =B(I,32)
      BOB40  =B(I,33)
      BOB60  =B(I,34)
C
      SSEGL  =B(I,35)
      HH     =B(I,36)
      PH=B(I,36)
      RML    =B(I,37)
      V      =B(I,38)
      WEB    =B(I,41)
      TPLATE=B(I,41)
      FLOWL  =B(I,42)
C
      PSOIL  =B(I,30)
      PTOTAL=B(I,31)
      PWATER=B(I,43)
C     LABOR COST FACTOR IN COMPRESSED AIR
      CFLCA=AIRPR**2/400.+1.5
      IF(NSSTYP.NE.2.OR.AIRPR.LE.0.) CFLCA=1.
C
C     ------------------------------------------------------------------
C     CALCULATE SETUP COST  FOR SHAFT SEGMENT I
      CALL CSETUP(A,B,NSEGS,NSSEG1,BE,HH,ITYPE,I   ,SETUSH,SETUPM,SETUPR,
     1 CLES,CEES,CMES,CFLWWK,CFEWWK,NSSTYP,DSES,DMES,DRES,NTSMAX,NSSMAX)
C     ------------------------------------------------------------------
C
C     CALCULATE PUMPING TIME
      PUMPTM=0.
      IF(FLOWL.LE.0.) GO TO 700
      PUMPTM=(5.+14.*SETUSH+28.*SETUPM)/DTP+7./DAYS/AR
      AL=2.*HOURS
      IF(LINING.EQ.1) PUMPTM=PUMPTM+(30.+SHAFT(NSHAFT,8)/AL*7./DAYS)
     1                  /DTP
      IF(LINING.EQ.2) PUMPTM=PUMPTM+30./DTP
  700 CONTINUE
C     ------------------------------------------------------------------
C     CALCULATE COST OF EXCAVATION IN SHAFT SEGMENT I
      CALL COEX(CLE,CEE,CME,ITYPE,MEX,AR,BE,RS,ISHAPS,SFA,SFP,
     1          PSOIL,STABNO,DTRNCH,DROCK,SIDESL,VBOX,VSOIL,VROCK,PHI,
     2          DCENT,HOURS,Y,DM,MSTAB,CFLCA,CFLWWK,CFEWWK,NSSTYP)
C     ------------------------------------------------------------------
C     CALCULATE COST OF MUCK LOADING IN SHAFT SEGMENT I
      CALL CMUKLD(CLML,CEML,CMML,ITYPE,MEX,AR,DM,V,Y,RML,RMLMAX,
     1                 MSTAB,CFLCA,CFLWWK,CFEWWK,HOURS)
C     ------------------------------------------------------------------
C     CALCULATE MUCK HOISTING COSTS FOR SHAFT SEGMENT I
      CALL CMTAH(CLMT,CEMT,CMMT,CLMH,CEMH,CMMH,ITYPE,MTM,DM,AR,
     1HSFA,V,HH,LINING,RML,RMLMAX,HSLOPE,BE,ISHAPS,RL,UCLT,UCET,Y,UCLMH,
     2HSCA,UCEMH,MSTAB,DLOCK,CLIND,HOURS,OPEN,DCENT,VBACEX,VBACDS,VBOX,
     3    VSOIL,VROCK,TOTBOX,CFLWWK,CFEWWK,CFLCA,DDS,NSSTYP,DTRNCH,DROCK)
C     ------------------------------------------------------------------
C     CALCULATE MUCK DISPOSAL COST FOR SHAFT SEGMENT I
      CALL CMUKDP(CLMD,CEMD,CMMD,AR,V,CDS,DDS,VDS,NSSTYP,HOURS,
     1          CFLWWK,CFEWWK,ITYPE)
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(Continued)

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C     ------------------------------------------------------------------
C      CALCULATE COST OF SHAFT SUPPORTS  FOR SHAFT SEGMENT I
       CALL CTSUP(CLTS,CETS,CMTS,RQD,MEX,ISHAPS,BE,AR,RS,BE40,BE60,ITYPE,
     1     Y,DM,NSSTYP,BF,ISUPPT,TPLATE,TSEG,PSOIL,WEB,PTOTAL,BOB,LINWT,
     2     MSTAB,CFLCA,HOURS,CFLWWK,CFEWWK,DSLURY,DTRNCH,IDECK,DROCK,
     3     WTSTRT,WTWALE,SPDLT,WTSPD,WTSP,WTANCH,TOTBOX,IBRACE,SFA)
C     ------------------------------------------------------------------
C      CALCULATE COST OF LINING AND FORMWORK IN SHAFT SEGMENT I
       CALL LINING1(CLL,CEL,CML,CLFW,CEFW,CMFW,ITYPE,LINING,RQD,MEX,
     1WEB,TL,BOB,BOB40,BF,Y,DM,BOB60,ISHAPS,BE,UCLT,UCET,MTM,
     2UCLMH,UCEMH,SFA,NOFORM,AR,NSSTYP,PSOIL,PWATER,VL,SFP,
     3FORMAR,HOURS,CFLCA,CFLWWK,CFEWWK)
C     ------------------------------------------------------------------
C      CALCULATE GROUTING COSTS FOR SHAFT SEGMENT I
       CALL CGROUT(CLG,CEG,CMG,ITYPE,GI,ISHAPS,BE,AR,RS,NSSTYP,MSTAB,
     1           DTUN,HH,HOURS,CFLWWK,CFEWWK,SSEGL,PERM,SFP,DTG,TIMEG)
C     ------------------------------------------------------------------
C      CALCULATE COST OF PUMPING FOR SHAFT SEGMENT I
       CALL CPUMP(CLP,CEP,CMP,NSSTYP,FLOW,PH,PIPL,AR,ITYPE,
     1          ELSURF,ELBOTM,DAYS,LINING,PUMPTM,MEX,DTRNCH,DROCK,FLOWL,
     2          WELLS,RL,TIMEDW,ISUPPT,ELWATR,ELNPB,IWATER,CFLWWK,CFEWWK)
C     ------------------------------------------------------------------
C      CALCULATE COST OF AIR CONDITIONING  AND COMPRESSED AIR
C      FOR SHAFT SEGMENT I
       CALL CAIRC(CLAC,CEAC,CMAC,Q,QT,BE,BF,AR,HOURS,NSSTYP,MSTAB,ITYPE,
     1          AIRPR,    SFA,ISHAPS,HH,CAVT,ALOCK,DTC,DTCA,PUMPLT,DM,
     2           ALOCKL,UCMCP,CFLWWK,CFEWWK,DAYS,Y,PERM)
C     ------------------------------------------------------------------
C
C
C     ------------------------------------------------------------------
       IF(LIST(7).EQ.1) GO TO 810
       IF(NLINES+11.LT.60) GO TO 810
       WRITE(LO,2000)
       NLINES=6
C     ------------------------------------------------------------------
C      CALCULATE COST FACTORS
   810 POP=(1.+0.01*OM)*(1.+0.01*PM)
C      CF(1),CF(2) AND CF(3) ARE COMPOSITE COST FACTORS FOR L, E, AND M
       CFL=SHAFT(NSHAFT,12)
       CFE=SHAFT(NSHAFT,13)
       CFM=SHAFT(NSHAFT,14)
       RCF=SHAFT(NSHAFT,15)
       CF(1)=POP*CFL*RCF
       CF(2)=POP*CFE*RCF
       CF(3)=POP*CFM*RCF
C     ------------------------------------------------------------------
C      MULTIPLY BY COMPOSITE COST FACTORS AND THEN OBTAIN SEGMENT
C      COSTS PER FOOT TO THE NEAREST DOLLAR
       IL( 1)=CLES*CF(1)+.5
       IE( 1)=CEES*CF(2)+.5
       IM( 1)=CMES*CF(3)+.5
       IL( 2)=CLE *CF(1)+.5
       IE( 2)=CEE *CF(2)+.5
       IM( 2)=CME *CF(3)+.5
       IL( 3)=CLML*CF(1)+.5
       IE( 3)=CEML*CF(2)+.5
       IM( 3)=CMML*CF(3)+.5
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      IL( 4)=CLMH*CF(1)+.5
      IE( 4)=CEMH*CF(2)+.5
      IM( 4)=CMMH*CF(3)+.5
      IL( 5)=CLMD*CF(1)+.5
      IE( 5)=CEMD*CF(2)+.5
      IM( 5)=CMMD*CF(3)+.5
      IL( 6)=CLTS*CF(1)+.5
      IE( 6)=CETS*CF(2)+.5
      IM( 6)=CMTS*CF(3)+.5
      IL( 7)=CLL *CF(1)+.5
      IE( 7)=CEL *CF(2)+.5
      IM( 7)=CML *CF(3)+.5
      IL( 8)=CLFW*CF(1)+.5
      IE( 8)=CEFW*CF(2)+.5
      IM( 8)=CMFW*CF(3)+.5
      IL( 9)=CLG *CF(1)+.5
      IE( 9)=CEG *CF(2)+.5
      IM( 9)=CMG *CF(3)+.5
      IL(10)=CLP *CF(1)+.5
      IE(10)=CEP *CF(2)+.5
      IM(10)=CMP *CF(3)+.5
      IL(11)=CLAC*CF(1)+.5
      IE(11)=CEAC*CF(2)+.5
      IM(11)=CMAC*CF(3)+.5
C     ---------------------------------------------------------------
C     CALCULATE SEGMENT COST/FOOT FOR LABOR, EQUIPMENT AND MATERIALS
      SLCPF=0
      SECPF=0
      SMCPF=0
      DO 815 LL=1,11
      SLCPF=SLCPF+IL(LL)
      SECPF=SECPF+IE(LL)
  815 SMCPF=SMCPF+IM(LL)
      TSCPF=SLCPF+SECPF+SMCPF
C     ---------------------------------------------------------------
C     CALCULATE TOTAL SEGMENT COST/FOOT FOR EACH COST COMPONENT
      TCES = IE( 1)+IM( 1)+IL( 1)
      TCE  = IE( 2)+IM( 2)+IL( 2)
      TCML = IE( 3)+IM( 3)+IL( 3)
      TCMH = IE( 4)+IM( 4)+IL( 4)
      TCMD = IE( 5)+IM( 5)+IL( 5)
      TCTS = IE( 6)+IM( 6)+IL( 6)
      TCL  = IE( 7)+IM( 7)+IL( 7)
      TCFW = IE( 8)+IM( 8)+IL( 8)
      TCG  = IE( 9)+IM( 9)+IL( 9)
      TCP  = IE(10)+IM(10)+IL(10)
      TCAC = IE(11)+IM(11)+IL(11)
C     ---------------------------------------------------------------
C     CALCULATE TOTAL SEGMENT COSTS IN THOUSANDS OF DOLLARS
      TLC = SLCPF*SSEGL/1000.
      TEC = SECPF*SSEGL/1000.
      TMC = SMCPF*SSEGL/1000.
      TSC = TLC+TEC+TMC
C     ---------------------------------------------------------------
      IF(LIST(7).EQ.1) GO TO 840
C     WRITE OUT THE SEGMENT COSTS FOR LABOR, EQUIP, MAT, AND TOTAL
      ISSEGL=SSEGL
      NSSEG=B(I,2)
```

(Continued)

```
      WRITE(LO,2001) NSHAFT,NSSEG,(IL(JJJ),JJJ=1,11),SLCPF,TLC
      WRITE(LO,2002)           (IE(JJJ),JJJ=1,11),SECPF,TEC
      WRITE(LO,2003)           (IM(JJJ),JJJ=1,11),SMCPF,TMC
      WRITE(LO,2004) TCES,TCE,TCML,TCMH,TCMD,TCTS,TCL,TCFW,
     1 TCG,TCP,TCAC,TSCPF,ISSEGL,TSC
C
      NLINES=NLINES+5
C
C     ACCUMULATE SHAFT SEGMENT COSTS INTO COST OF SHAFT
  840 SCL=SCL+TLC
      SCE=SCE+TEC
      SCM=SCM+TMC
      SCT=SCL+SCE+SCM
C     END OF COSTS ON A SEGMENT BASIS
  900 CONTINUE
C     ----------------------------------------------------------------
C     LIST OUT TOTAL COST OF SHAFT
  850 IF(LIST(7).EQ.1) GO TO 860
      WRITE(LO,1004) SHAFT(NSHAFT,12),SCL,SHAFT(NSHAFT,15),
     1 SHAFT(NSHAFT,13),SCE,SHAFT(NSHAFT,14),SCM,CFLWWK,SCT,CFEWWK
      NLINES=NLINES+7
C
C     ----------------------------------------------------------------
C     ACCUMULATE COSTS OF ALL SHAFTS
  860 SFTTLC=SFTTLC+SCL
      SFTTEC=SFTTEC+SCE
      SFTTMC=SFTTMC+SCM
      SFTTC=SFTTLC+SFTTEC+SFTTMC
C
      SHAFT(NSHAFT,19)=SCL
      SHAFT(NSHAFT,20)=SCE
      SHAFT(NSHAFT,21)=SCM
      SHAFT(NSHAFT,22)=SCT
C     END OF COSTS ON A SHAFT BASIS
  950 CONTINUE
C     ----------------------------------------------------------------
C     PRINT REACH COST SUMMARIES
      IF(LIST(8).EQ.1) GO TO 965
      WRITE(LO,1500)
      NLINES=5
      DO 960 NREACH=1,NTRMAX
      IF(TRDATA(NREACH,1).LT.-10.E29) GO TO 960
      NSHAFT=TRDATA(NREACH,1)
      RCL=TRDATA(NREACH,17)
      RCE=TRDATA(NREACH,18)
      RCM=TRDATA(NREACH,19)
      RCT=TRDATA(NREACH,20)
      WRITE(LO,1501) NREACH,NSHAFT,SHAFT(NSHAFT,15),(SHAFT(NSHAFT,JJ),
     1 JJ=12,14),RCL,RCE,RCM,RCT
      NLINES=NLINES+2
      IF(NLINES.LT.58) GO TO 960
      WRITE(LO,1500)
      NLINES=5
  960 CONTINUE
  965 CONTINUE
C     ----------------------------------------------------------------
C     PRINT SHAFT COST SUMMARIES
      IF(LIST(9).EQ.1) GO TO 975
```

(Continued)

```
      WRITE(LO,1600)
      NLINES=5
      DO 970 NSHAFT=1,NSMAX
      IF(SHAFT(NSHAFT,1).LT.-10.E29) GO TO 970
      SCL=SHAFT(NSHAFT,19)
      SCE=SHAFT(NSHAFT,20)
      SCM=SHAFT(NSHAFT,21)
      SCT=SHAFT(NSHAFT,22)
      WRITE(LO,1601) NSHAFT,SHAFT(NSHAFT,15),(SHAFT(NSHAFT,JJ),JJ=12,14)
     1 ,SCL,SCE,SCM,SCT
      NLINES=NLINES+2
      IF(NLINES.LT.58) GO TO 970
      WRITE(LO,1600)
      NLINES=5
  970 CONTINUE
  975 CONTINUE
C     ---------------------------------------------------------------
C     TOTAL PROJECT CONSTRUCTION COSTS
      TLABOR=TUNLC+SFTTLC
      TEQUIP=TUNEC+SFTTEC
      TMATER=TUNMC+SFTTMC
      TCOST=TUNTC+SFTTC
C     ---------------------------------------------------------------
C     PRINT PROJECT SUMMARY SHEET
      WRITE(LO,2) TITLE
      WRITE(LO,1005) PM,TUNLC,OM,TUNEC,TUNMC,TUNTC
      WRITE(LO,1006) SFTTLC,SFTTEC,SFTTMC,SFTTC
      WRITE(LO,1007) TLABOR,TEQUIP,TMATER,TCOST
C     ---------------------------------------------------------------
      RETURN
C
C     ---------------------------------------------------------------
    2 FORMAT(1H1,10(/),50X,70(1H*),/,50X,1H*,68X,1H*,
     110(/,50X,1H*,2X,16A4,2X,1H*),
     3     /,50X,1H*,68X,1H*,/,50X,70(1H*),///)
 1004 FORMAT(1X,119(1H-),//, 7X, 14HREGIONAL  COST,6X,10HCOST INDEX,10X
     110H -- LABOR ,F5.2,      5X,25HSHAFT LABOR COST ........,I9/
     2 7X,9HFACTOR    ,F5.2,26X,10HEQUIPMENT ,F5.2,5X,
     3                              25HSHAFT EQUIPMENT COST ....,I9/
     4 47X,10HMATERIALS ,F5.2,      5X,25HSHAFT MATERIALS COST ....,I9/
     5 41X,16HLABOR WORK WEEK ,F5.2,5X,25HSHAFT COST ..............,I9/
     6 41X,16HEQUIP WORK WEEK ,F5.2)
 1005 FORMAT(50X,17HPROFIT MARGIN     ,F5.2,3X,
     1                36HTOTAL TUNNEL  LABOR COST.....($1000),I9/,
     2    50X,17HOVERHEAD MARGIN   ,F5.2,3X,
     3                36HTOTAL TUNNEL  EQUIPMENT COST.........,I9/,
     4            75X,36HTOTAL TUNNEL  MATERIAL COST..........,I9/,
     5            75X,36HTOTAL TUNNEL  COST...................,I9/)
 1006 FORMAT(//,75X,36HTOTAL  SHAFT  LABOR COST..............,I9/
     1              75X,36HTOTAL  SHAFT  EQUIPMENT COST.........,I9/
     2              75X,36HTOTAL  SHAFT  MATERIAL COST..........,I9/
     3              75X,36HTOTAL  SHAFT  COST...................,I9)
 1007 FORMAT(//,75X,35HTOTAL PROJECT LABOR COST ...........,I10/
     1         75X,35HTOTAL PROJECT EQUIPMENT COST........,I10/
     2         75X,35HTOTAL PROJECT MATERIAL COST.........,I10/
     3         75X,35HTOTAL PROJECT COST.................,     I10)
 1500 FORMAT(1H1,1X,34(1H*),50H  T U N N E L  R E A C H  C O S T  S U M
     1M A R Y  ,35(1H*)//    14X,19HEXIT     REGIONAL  ,6(1H*),
```

(Continued)

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     2 12HCOST INDEXES,6(1H*),10X,17(1H*),15H COSTS ($1000) ,16(1H*)/,
     3 3X,52HREACH        SHAFT   COST FACTOR  LABOR   EQUIP   MATL,
     4 16X,41HLABOR    EQUIPMENT    MATERIAL       TOTAL,/,1X,119(1H-)/)
 1501 FORMAT(4X,I3,8X,I3,7X,F4.2,2X,3(4X,F4.2),11X,4(3X,I9)/)
 1600 FORMAT(1H1,1X,41(1H*),37H  S H A F T  C O S T  S U M M A R Y ,
     1 41(1H*)//    23X,10HREGIONAL  ,6(1H*),12HCOST INDEXES,6(1H*),
     2 10X,17(1H*),15H COSTS ($1000) ,16(1H*)/,3X,5HSHAFT,14X,
     3 33HCOST FACTOR  LABOR   EQUIP   MATL,16X,
     4 41HLABOR   EQUIPMENT    MATERIAL       TOTAL,/,1X,119(1H-)/)
 1601 FORMAT(4X,I3,18X,F4.2,2X,3(4X,F4.2),11X,4(3X,I9)/)
 2000 FORMAT(1H1,45(1H*),23H  S H A F T   C O S T  ,52(1H*)//
     1120H SHAFT SEG  *************** COST IN DOLLARS PER FOOT OF SHAFT
     2*************** SEG   SEGMENT  SEGMENT                          /
     3120H  NO    NO    EXC    EXC  MUCK  MUCK  MUCK SUP-   LIN-   LIN GR
     4OUT PUMP-  AIR-  COST  LENGTH    COST                            /
     5120H             SETUP          LOAD HOIST  DISP PORTS   ING  FORM
     6       ING  COND ($/FT)  (FEET)  ($1000)
     7   /,1X,119(1H-))
 2001 FORMAT(/,1X,I3,I5,2H L,12I6,8X,I10)
 2002 FORMAT(9X,       2H E,12I6,8X,I10)
 2003 FORMAT(9X,       2H M,12I6,8X,I10)
 2004 FORMAT(9X,       2H T,12I6,I8,I10)
 3005 FORMAT(1H1,6H SHAFT,I4,' IS A PORTAL OR A DUMMY SHAFT     ALL CO
     1STS ARE ZERO')
C     ----------------------------------------------------------------
C
      RETURN
      END
      SUBROUTINE CUINFA(A,CNP,CUMSL,HH,NPBS,NSEGS,RMLMAX,DTCA,NRSEG1,
     1CLIND,UCMCP,NTSMAX,NPMAX)
      DIMENSION  A(NTSMAX,68),             CNP(NPMAX,2),CUMSL(NPMAX)
C     ----------------------------------------------------------------
C     THIS SUBROUTINE COMPUTES THE TOTAL LENGTH OF SEGMENTS WHICH ARE
C     EXCAVATED IN FREE AIR BUT NEED CONVEYOR BELT FOR FURTHER
C     EXCAVATION IN COMPRESSED AIR.  IT ALSO COMPUTES THE COST OF
C     COMPRESSED AIR PIPING
C     ----------------------------------------------------------------
      DTFACN=0.
      UCMCP=0.
      NSEGSA=IABS(NSEGS)
C     ----------------------------------------------------------------
      DO 100 I=1,NSEGSA
      J=NSEGSA-I+1
      N=NRSEG1+J-1
      IF(NSEGS.LT.0) N=NRSEG1-J+1
      MSTAB=A(N,31)
      DM=A(N,46)
      TSEGL=A(N,45)
C     CHECK LAST SEGMENT IN THE REACH AND SET LOCK POSITION
      IF(I.EQ.1) NPLOCK=A(N,2)
C     CHECK THE POSITION OF AIR LOCK FOR THIS SEGMENT WITH THE POSITION
C     FOR THE NEXT SEGMENT IN COMPRESSED AIR
      IF( ABS(A(N,36)).EQ.NPLOCK) GO TO 50
C     CHECK IF THE SEGMENT IN COMPRESSED AIR
      IF(MSTAB.NE.1) GO TO 100
   10 NPLOCK= ABS(A(N,36))
      DLOCK=ABS(CUMSL(NPLOCK)-CUMSL(NPBS))
C     FIND THE SURFACE NODAL POINT OF AIR LOCK
```

(Continued)

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      DO 80 K=1,J
      IF(NSEGS.LT.0) GO TO 60
      NN=NRSEG1+K-1
      NPREND=A(NN,2)
      NPS=A(NN,17)
      GO TO 70
   60 NN=NRSEG1-K+1
      NPREND=A(NN,3)
      NPS=A(NN,18)
   70 IF(NPLOCK.EQ.NPREND) GO TO 90
   80 CONTINUE
C     CALCULATE COST OF COMPRESSED AIR PIPING
   90 DTHLOK=CNP(NPS,2)-CNP(NPLOCK,2)
      PUMPLT=DM*5280.-DLOCK+DTHLOK
      CAVT=A(N,35)
      UCMCP=UCMCP+(26.+0.0018*CAVT-0.000000015*CAVT**2)*PUMPLT/DTCA
      GO TO 100
   50 IF (MSTAB.NE.1) DTFACN=DTFACN+TSEGL
      IF(MSTAB.EQ.1.AND.I.EQ.1) GO TO 10
  100 CONTINUE
C     COMPUTE THE INSTALLATION COST OF CONVEYOR IN THE FREE AIR SEGMENTS
      CLIND=(0.31*SQRT(RMLMAX+40.)+1.38)*DTFACN/DTCA
      RETURN
      END
      SUBROUTINE LOCKLT(A,NSEGS,RMLMAX,MTM,ALOCK,ALOCKL,NTSMAX,NRSEG1)
      DIMENSION A(NTSMAX,68)
C     ------------------------------------------------------------------
C
C     LOCKLT COMPUTES NUMBER OF AIR LOCK LOCATIONS AND LENGTH OF AIR
C     LOCK IN A REACH
C     ------------------------------------------------------------------
      ALOCK=1.
      ALOCKL=30.
      M=0
      NSEGSA=IABS(NSEGS)
C     ------------------------------------------------------------------
C     NUMBER OF AIR LOCK LOCATIONS IN REACH
      DO 100 II=1,NSEGSA
      I=NRSEG1+(II-1)*NSEGS/NSEGSA
      MSTAB=A(I,31)
      IF(MSTAB.NE.1) GO TO 100
      M=M+1
C     FIRST COMPRESSED AIR SEGMENT
      IF(M.NE.1) GO TO 10
      NPLOCK=A(I,36)
      IF(NPLOCK.LT.0) M=-1000000
   10 IF(NPLOCK.NE.A(I,36)) ALOCK=ALOCK+1.
C     ------------------------------------------------------------------
C     LENGTH OF AIR LOCK
      IF(MTM.NE.3) GO TO 100
      AR=A(I,8)
      DM=A(I,46)
      CARS=(1.+0.7/(DM+2.))*RMLMAX*(0.06+0.12*DM**0.333
     1    +AR*(0.06+0.023*DM-0.12*DM**0.333)/300.)
      IF(CARS.LT.1.) CARS=1.
      ENGINE=CARS/11.
      IF(ENGINE.LT.1.) ENGINE=1.
      ALOKLT=17.*(CARS/ENGINE+1.)
      IF(ALOCKL.LT.ALOKLT) ALOCKL=ALOKLT
```

(Continued)

```
  100 CONTINUE
C     -----------------------------------------------------------------
C     ALOCK = NEGATIVE FOR COOLING PLANT FOR FIRST LOCK MOVED FROM SHAFT
C     TO GROUND SURFACE ABOVE SECOND LOCK POSITION
      IF(M.LT.0) ALOCK=-ALOCK
      RETURN
      END
      SUBROUTINE CSETUP(A,B,NSEGS,NSEG1,BE,HH,ITYPE,I,SETUSH,SETUPM,
     1SETUPR,CLES,CEES,CMES,CFLWWK,CFEWWK,NSTYP,DSES,DMES,DRES,NTSMAX,
     2NSSMAX)
C     -----------------------------------------------------------------
C     CSETUP DETERMINES THE AVERAGE COSTS INVOLVED IN SETTING UP THE
C     NECESSARY EQUIPMENT TO EXCAVATE EACH SEGMENT
C     -----------------------------------------------------------------
      DIMENSION  A(NTSMAX,68),B(NSSMAX,43)
C     -----------------------------------------------------------------
      IF(NSTYP.EQ.3) GO TO 500
C     INITIALIZE
      UCLSS=0.
      UCESS=0.
      UCMSS=0.
      UCLMS=0.
      UCEMS=0.
      UCMMS=0.
      UCLRS=0.
      UCERS=0.
      UCMRS=0.
C     -----------------------------------------------------------------
      IF(ITYPE.EQ.2) GO TO 200
C     TUNNEL
C     FIRST SEGMENT IN THE REACH
      IF(I.NE.NSEG1) GO TO 150
C     DETERMINE THE TOTAL LENGTH OF SHIELD, MOLE AND RIPPER EXCAVATED
C     SEGMENTS IN A REACH
      DSES=0.0000001
      DMES=0.0000001
      DRES=0.0000001
      NSEGSA=IABS(NSEGS)
      DO 100 NN=1,NSEGSA
      M=NSEG1+(NN-1)*NSEGS/NSEGSA
      MEX=A(M,7)
      TSEGL=A(M,45)
      IF(MEX.LE.1.OR.MEX.GE.6) GO TO 100
C     SHIELD
      IF(MEX.GE.3) DSES=DSES+TSEGL
C     MOLE
      IF(MEX.LE.3) DMES=DMES+TSEGL
C     RIPPER
      IF(MEX.EQ.5) DRES=DRES+TSEGL
  100 CONTINUE
  150 MEX=A(I,7)
      IF(MEX.LE.1.OR.MEX.GE.6) GO TO 400
C     SHIELD SET UP COSTS
      IF(MEX.LT.3) GO TO 160
      UCLSS=(20000.+3.*HH+45.*BE**2)*SETUSH
      UCESS=(2000.+0.04*BE*HH+21.*BE**2)*SETUSH
      UCMSS=(700.+0.1*HH+2.5*(BE-6.)**2)*SETUSH
C     MOLE SETUP COSTS
```

(Continued)

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  160 IF(MEX.GT.3) GO TO 170
      UCLMS=(50000.+15.*HH+152.*(BE+12.)**2)*SETUPM
      UCEMS=(25000.+6.*HH+234.*(BE-10.)**2)*SETUPM
      UCMMS=25.*BE**2*SETUPM
C     RIPPER SETUP COSTS
  170 IF(MEX.NE.5) GO TO 400
      UCLRS=(4000.+HH*(1.+0.05*BE)+6.8*BE**2)*SETUPR
      UCERS=(1000.+0.7*HH+1.5*(BE+5.)**2)*SETUPR
      UCMRS=(150.+0.09*HH+0.2*BE**2)*SETUPR
      GO TO 400
C     ----------------------------------------------------------------
C     SHAFT
  200 IF(I.NE.NSEG1) GO TO 350
      DSES=0.0000001
      DMES=0.0000001
      DRES=0.0000001
C     DETERMINE THE TOTAL LENGTH OF SHIELD AND MOLE EXCAVATED
C     SEGMENTS IN A SHAFT
      SETUSH=0.
      SETUPM=0.
      DO 300 NN=1,NSEGS
      M=NSEG1+NN-1
      MEX=B(M,7)
      SSEGL=B(M,35)
      IF(MEX-2) 300,220,210
C     SHIELD
  210 DSES=DSES+SSEGL
      IF(SETUSH.LT.1.) SETUSH=1.
      IF(MEX.EQ.4) GO TO 300
C     MOLE
  220 DMES=DMES+SSEGL
      IF (SETUPM.LT.1.) GO TO 250
      IF(MEX.EQ.2.AND.MEXP.EQ.3) SETUPM=SETUPM+0.125
      GO TO 300
  250 SETUPM=1.
  300 MEXP=MEX
C     ----------------------------------------------------------------
  350 MEX=B(I,7)
C     SHIELD SETUP COSTS
      IF(MEX.LT.3) GO TO 360
      UCLSS=(2000.+930.*BE)*SETUSH
      UCESS=(500.+14.*(BE-5.)**2)*SETUSH
      UCMSS=(300.+(BE-3.)**2)*SETUSH
C     MOLE SETUP COSTS
  360 IF(.NOT.(MEX.EQ.2.OR.MEX.EQ.3)) GO TO 400
      UCLMS=(130.*(BE+5.)**2+65000.)*SETUPM
      UCEMS=(165.*(BE-10.)**2+20000.)*SETUPM
      UCMMS=(30.*(BE-10.)**2+3200.)*SETUPM
C     ----------------------------------------------------------------
C     TOTAL SETUP COSTS
  400 CLES=(UCLSS/DSES+UCLMS/DMES+UCLRS/DRES)*CFLWWK
      CEES=(UCESS/DSES+UCEMS/DMES+UCERS/DRES)*CFEWWK
      CMES=UCMSS/DSES+UCMMS/DMES+UCMRS/DRES
      RETURN
C
  500 CLES=0.
      CEES=0.
      CMES=0.
```

(Continued)

```
      RETURN
      END
      SUBROUTINE COEX(CLE,CEE,CME,ITYPE,MEX,AR,BE,RS,ISHAPE,SFA,SFP,
     1                PSOIL,STABNO,DTRNCH,DROCK,SIDESL,VBOX,VSOIL,VROCK,FHI,
     2                DCENT,HOURS,V,DM,MSTAB,CFLCA,CFLWWK,CFEWWK,NSTYP)
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C     COEX CALCULATES EXCAVATION COSTS IN TUNNELS AND SHAFTS
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
      IF(NSTYP.NE.2) GO TO 110
C     CALCULATE WEIGHT OF SHIELD
      F=1.
      IF(ISHAPE.EQ.3) F=1.56
      IF(ITYPE.EQ.2.AND.ISHAPE.EQ.2) F=2.
      WTSHLD=(0.037*SQRT(81.+F*BE**2)-0.038)*PSOIL*STABNO**2*SFP
C     ----------------------------------------------------------------
  110 IF(ITYPE.EQ.2) GO TO 100
C     CALCULATE UNIT COST OF TUNNEL EXCAVATION
C     CHECK TUNNEL EXCAVATION METHODS
      GO TO (120,220,320,420,520,620,620),MEX
C     ROCK TUNNEL
C     CONVENTIONAL EXCAVATION
  120 GO TO (121,122,123),ISHAPE
C     SHAPE IS CIRCLE
  121 UCL=0.07*(BE+40.)**2-100.
      UCE=0.046*(BE+15.)**2
      UCM=SFA*SQRT(RS)*BE**2/2000.+(0.11*(BE+10.)**2-25.)/AR
      GO TO 124
C     SHAPE IS HORSESHOE
  122 UCL=0.08*(BE+40.)**2-110.
      UCE=0.05*(BE+15.)**2+4.
      UCM=SFA*SQRT(RS)*BE**2/2000. + (0.12*(BE+10.)**2-22.)/AR
      GO TO 124
C     SHAPE IS BASKETHANDLE
  123 UCL=0.1*BE**2+60.
      UCE=0.04*(BE+5.)**2+17.
      UCM=SFA*SQRT(RS)*BE**2/2000. + (0.13*(BE-5.)**2+14.)/AR
  124 CONTINUE
      GO TO 800
C     MOLE EXCAVATION
  220 UCL=0.021*BE**2+55.
      UCE=0.048*BE**2
      UCM=(5000.+RS+120000./AR)*BE**2/220000.
      GO TO 800
C     ----------------------------------------------------------------
C     SOFT GROUND TUNNEL
C     MOLED
  320 UCL=(55.+0.021*BE**2)*CFLCA
      UCE=0.048*BE**2+0.000035*WTSHLD
      UCM=(0.045+0.02*HOURS/AR)*BE**2+(0.5+0.05*BE)*HOURS/AR
      GO TO 800
C     HAND EXCAVATED
  420 UCL=(0.1*(BE+5.)**2+30.)*CFLCA
      UCE=0.02*(BE+7.)**2+0.000035*WTSHLD
      UCM=(0.5+0.25*BE)*HOURS/AR
      GO TO 800
C     RIPPER EXCAVATED
```

(Continued)

```
  520 UCL=(50.+0.01*(BE+4.)**2)*CFLCA
      UCE=12.+0.2*BE+0.000035*UTSHLD
      UCM=(2.0+0.09*BE)*HOURS/AR
      GO TO 800
C     ****************************************************************
C     CUT AND COVER
  620 IF(DROCK.GE.DTRNCH) GO TO 700
C     OPEN CUT INVOLVING ROCK EXCAVATION
      VROCK=BE*(DTRNCH-DROCK)/27.
      UCLROK=71.+0.55*AR*VROCK/HOURS
      UCEROK=15.+(0.4+0.0035*DTRNCH)*AR*VROCK/HOURS
      UCMROK=(1.1+0.0006*(DTRNCH+DROCK))*VROCK
      IF(UCLROK.LT.84.75) UCLROK=84.75
      IF(AR*VROCK/HOURS.LT.25.) UCEROK=15.+(0.4+0.0035*DTRNCH)*25.
      IF(DROCK.GT.0.) GO TO 650
C     ALL ROCK , NO SOIL EXCAVATION
      VSOIL=0.
      DCENT=0.
      UCLSOL=0.
      UCESOL=0.
      UCMSOL=0.
      GO TO 750
C     SOME ROCK, SOME SOIL EXCAVATION
C     ----------------------------------------------------------------
C     SOIL EXCAVATION
  650 VSOIL=(BE+DROCK*SIDESL)*DROCK/27.
      DCENT=DROCK*(1.5*BE+DROCK*SIDESL)/(BE+DROCK*SIDESL)/3.
      IF(SIDESL.LT.1.) GO TO 670
      IF(AR*VSOIL/HOURS.LE.500.) GO TO 670
C     SOIL EXCAVATED BY SCRAPERS
  660 SCRAPR=AR*VSOIL/HOURS/(290.-0.9*DCENT)
      IF(SCRAPR.LT.1.) SCRAPR=1.
      PUSHER=SCRAPR/4.
      IF(PUSHER.LT.1.) PUSHER=1.
      UCLSOL=17.+8.0*(SCRAPR+PUSHER)
      UCESOL=19.*SCRAPR+10.*PUSHER
      UCMSOL=(5.5*SCRAPR+3.0*PUSHER)*HOURS/AR
      GO TO 750
C     SOIL EXCAVATED BY DRAGLINE
  670 BUCMIN=10.-0.7*SQRT(160.-DROCK)
  680 BUCKET=2.5*(AR*VSOIL/HOURS/(1.05-0.00014*(PHI-50.)**2)-40.)
     1      /(170.-DCENT)
      IF(BUCKET.LT.BUCMIN) BUCKET=BUCMIN
      UCLSOL=19.0
      UCESOL=13.0+0.85*BUCKET**2
      UCMSOL=1.1*BUCKET*VSOIL/(40.+0.4*(170.-DCENT)*BUCKET)
     1      /(1.05-0.00014*(PHI-50.)**2)
      GO TO 750
C     ----------------------------------------------------------------
C     SOIL EXCAVATION ONLY, NO ROCK EXCAVATION
  700 VROCK=0.
      UCLROK=0.
      UCEROK=0.
      UCMROK=0.
      VSOIL=(BE+DTRNCH*SIDESL)*DTRNCH/27.
      DCENT=DTRNCH*(1.5*BE+DTRNCH*SIDESL)/(BE+DTRNCH*SIDESL)/3.
      IF(SIDESL.LT.1) GO TO 720
      IF(AR*VSOIL/HOURS.GT.500.) GO TO 660
```

(Continued)

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  720 BUCMIN=10.-0.7*SQRT(160.-DTRNCH)
      GO TO 600
C     ---------------------------------------------------------------------
C     COSTS OF BACKFILL
  750 V=VROCK+VSOIL
      UCLBAK=82.0
      UCEBAK=32.0
      IF(AR*(V-VBOX)/HOURS.LE.1200.) GO TO 760
      UCLBAK=82.*(V-VBOX)*AR/HOURS/1200.
      UCEBAK=32.*(V-VBOX)*AR/HOURS/1200.
  760 UCMBAK=0.01*(V-VBOX)
      UCL=UCLROK+UCLSOL+UCLBAK
      UCE=UCEROK+UCESOL+UCEBAK
      UCM=UCMROK+UCMSOL+UCMBAK
      GO TO 800
C     *********************************************************************
C     CALCULATE UNIT COSTS OF SHAFT EXCAVATION
  100 IF(NSTYP.EQ.3) GO TO 500
      GO TO (140,240,340,440),MEX
C     ROCK SHAFT
C     CONVENTIONAL
  140 UCL=30.+4.25*BE
      UCE=8.+2.2*BE
      UCM=(0.01+RS/2000000.)*BE**2 + (.8+RS/40000.+3.4/AR)*BE + 5.
      GO TO 800
      MOLED
  240 UCL=0.032*BE**2+84.
      UCE=0.072*BE**2
      UCM=(5000.+RS+120000./AR)*BE**2/150000.
      GO TO 800
C     ---------------------------------------------------------------------
C     SOFT GROUND SHAFT
C     MOLED
  340 UCL=(0.032*BE**2+84.0)*CFLCA
      UCE=0.072*BE**2+0.000035*WTSHLD
      UCM=(0.045+0.03*HOURS)*BE**2+(0.5+0.05*BE)*HOURS/AR
      GO TO 800
C     HAND/SHIELD
  440 IF(ISHAPE.EQ.1) UCL=63.0*CFLCA
      IF(ISHAPE.EQ.2) UCL=70.0*CFLCA
      UCE=7.40+0.000035*WTSHLD
      UCM=(3.70+0.05*BE)*HOURS/AR
  800 CLE=UCL*(HOURS*CFLWWK+Y*DM)/AR
      CEE=UCE*HOURS*CFEWWK/AR
      CME=UCM
      GO TO 900
C
  500 CLE=0.
      CEE=0.
      CME=0.
C
  900 RETURN
      END
      SUBROUTINE CMUKLD(CLML,CEML,CMML,ITYPE,MEX,AR,DM,V,Y,RMY,RMLMAX,
     1                  MSTAB,CFLCA,CFLWWK,CFEWWK,HOURS)
C     ---------------------------------------------------------------------
C     ---------------------------------------------------------------------
C     CMUKLD CALCULATES THE COST OF MUCK LOADING IN TUNNELS AND SHAFTS
```

(Continued)

```
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
      IF(MEX.EQ.1.OR.MEX.EQ.4) GO TO 100
C     ------------------------------------------------------------------
C
C     LOADING COSTS ARE ZERO FOR MOLE OR RIPPER EXCAVATION AND FOR
C     CUT-AND-COVER SEGMENTS
   50 CLML=0
      CEML=0
      CMML=0
      GO TO 300
C     ------------------------------------------------------------------
C     CHECK FOR TUNNEL OR SHAFT
  100 IF(ITYPE.EQ.2) GO TO 200
C     ------------------------------------------------------------------
C     TUNNELS
      UCL=9.30*CFLCA
      UCE=3.50
      IF(RMLMAX.GT.100.) UCE=6.60
      IF(RMLMAX.GT.300.) UCE=12.90
      UCM=0.02
      GO TO 250
C     ------------------------------------------------------------------
C     SHAFTS
  200 IF (MEX.EQ.4) GO TO 50
      UCL=9.30*CFLCA
      UCE=3.50
      UCM=1.50
C     ------------------------------------------------------------------
C     CALCULATE MUCK LOADING COSTS
  250 CLML=UCL*(HOURS*CFLWWK+V*DM)/AR
      CEML=UCE*HOURS*CFEWWK/AR
      CMML=UCM*V
  300 RETURN
      END
      SUBROUTINE CMTAH(CLMT,CEMT,CMMT,CLMH,CEMH,CMMH,ITYPE,MTM,DM,AR,
     1HSFA,V,HH,LINING,RML,RMLMAX,HSLOPE,BE,ISHAPE,RL,UCLT,UCET,Y,UCLMH,
     2HSCA,UCEMH,MSTAB,DLOCK,CLIND,HOURS,OPEN,DCENT,VBACEX,VBACDS,VBOX,
     3    VSOIL,VROCK,TOTBOX,CFLWWK,CFEWWK,CFLCA,DDS,NSTYP,DTRNCH,DROCK)
C
C     ------------------------------------------------------------------
C
C     CMTAH CALCULATES MUCK TRANSPORT COSTS IN TUNNELS AND MUCK HOISTING
C     COSTS IN TUNNELS AND SHAFTS.  IT ALSO CALCULATES COST OF TRANSPORT
C     FOR BACKFILL IN CUT-AND-COVER TUNNEL.
C     ------------------------------------------------------------------
C     SHAFT OR TUNNEL
      IF(ITYPE.EQ.2) GO TO 600
C
C     ------------------------------------------------------------------
      IF(NSTYP.EQ.3) GO TO 2000
C     COST OF MUCK TRANSPORT IN TUNNELS
      GO TO (20,60,40,80),MTM
C     ----------------------------------------
C     TRUCK TRANSPORT     Z= TRUCK VOLUME/4
   20 IF(ISHAPE.LE.2) Z=5.0 - 0.001*(70. - BE)**2
      IF(ISHAPE.EQ.3) Z=4.5 - 0.5*(BE-50.)**4/22000.
      TRUCKS=0.06*RMLMAX/Z*DM**0.7
      IF(TRUCKS.LT.1.) TRUCKS=1.
C     ----------------------------------------
```

(Continued)

```
      UCL=7.7*TRUCKS+7.1
      UCE=(1.5+3.1*Z)*TRUCKS
      UCM=0.05*(1.+0.77*ABS(HSLOPE))*DM
      GO TO 400
C     -------------------------------------------
C     RAIL TRANSPORT - FREE AIR
C     CALCULATION OF NUMBER OF CARS
   40 CONTINUE
      CARS=(0.06+0.12*DM**0.333)*RMLMAX
     1     + AR/300.*(0.06+0.023*DM-0.12*DM**0.333)*RMLMAX
      IF(MSTAB.EQ.1) GO TO 1000
   44 IF(CARS.LT.1.) CARS=1.
C     -------------------------------------------
C     CALCULATION OF NUMBER OF ENGINES
      ENGINE=CARS/11.
   55 IF(ENGINE.LT.1.) ENGINE=1.
      UCL=15.*ENGINE+7.14*(DM+1.)+AR/12.
      UCE=5.8*ENGINE+CARS+1.4*DM
      UCM=0.03*DM
      GO TO 400
C     -------------------------------------------
C     RAIL TRANSPORT - COMPRESSED AIR
C
 1000 DCR=0.1*DM*5280.
      DCA=DM-DLOCK/5280.
      IF(DCR.GT.500.) DCR=500.
      CARS=(1.+0.7/(DM+2.))*CARS
      IF(CARS.LT.1.) CARS=1.
      ENGINE=CARS/11.
      IF(ENGINE.LT.1.) ENGINE=1.
C     CALCULATE NUMBER OF CREWS INSIDE AND OUTSIDE THE AIR LOCK
      CREWAD=1.-ENGINE**4/4000.
      IF(CREWAD.LT.0.) CREWAD=0.
      CREWS=ENGINE+CREWAD
      CREWCA=1.+(CREWS-2.)*(DM*5280.-DLOCK-0.5*DCR)/(DM*5280.-1.5*DCR)
      IF(DLOCK.LT.DCR) CREWCA=CREWS-1.
      IF(DM*5280.-DLOCK.LT.0.5*DCR) CREWCA=1.
      UCL=1.5*(CREWS+(CFLCA-1.)*CREWCA)+AR*CFLCA/12.
     1    +7.14*(DM+1.)*(DLOCK/5280.+DCA*CFLCA)/DM
      UCE=9.3*ENGINE+CARS+1.4*DM
      UCM=0.033*DM
      GO TO 400
C     ------------------------------------------------------------
C     CONVEYOR TRANSPORT - FREE AIR
   60 UCL=(0.013*AR+0.6*DM)*SQRT(RMLMAX+40.)+0.06*AR-1.1*DM
      IF(HSLOPE.GE.0.0) UCECON=((1.+4.* HSLOPE)*SQRT(RMLMAX+40.)-26.*
     1  HSLOPE-1.5)*DM
      IF(HSLOPE.LT.0.0) UCECON=(SQRT(RMLMAX+40.)+6.* HSLOPE-1.5)*DM
      IF(HSLOPE.GE.0.0) UCMCON=(0.01+0.23*HSLOPE)*DM
      IF(HSLOPE.LT.0.0) UCMCON=0.01*DM
      UCEMT=0.
      UCMMT=0.
C     ------------------------------------------------------------
      IF(MSTAB.NE.1) GO TO 1100
C     CONVEYOR TRANSPORT - COMPRESSED AIR
      DCA=DM-DLOCK/5280.
      UCL=UCL*(DLOCK/5280.+DCA*CFLCA)/DM+7.7*CFLCA+16.8
C     COST OF MUCK TRANSFER IN AIR LOCK
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(Continued)

```
      UCEMT=8.10
      IF(RMLMAX.LE.100.) UCEMT=4.50
      IF(RMLMAX.GT.300) UCEMT=14.90
      UCMMT=0.02
 1100 UCE=UCECON+UCEMT
      UCM=UCMCON+UCMMT
C     STORE COST VALUES FOR USE IN LINING COMPUTATIONS  (SUB LINING)
      UCLT=(0.6*SQRT(RMLMAX+40.)-1.1)*DM
      UCET=UCE
      GO TO 400
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CONVEYOR AND TRUCK (FOR COMPRESSED AIR SEGMENT ONLY)
   80 IF(MSTAB.NE.1) GO TO 20
      IF(DLOCK.LE.0.001) GO TO 60
      DCA=DM-DLOCK/5280.
C     TRUCKS IN FREE AIR
      IF(ISHAPE.LE.2) Z=5.0 - 0.001*(70. - BE)**2
      IF(ISHAPE.EQ.3) Z=4.5 - 0.5*(BE-50.)**4/22000.
      TRUCKS=0.06*RMLMAX/Z*(DLOCK/5280.)**0.7
      IF(TRUCKS.LT.1.) TRUCKS=1.
      UCETR=(1.5+3.1*Z)*TRUCKS
      UCMTR=0.05*(1.+0.77*ABS(HSFA  ))*DLOCK/5280.
C     CONVEYOR IN COMPRESSED AIR
      UCECON=DCA*((1.+4.*HSCA   )*SQRT(RMLMAX+40.)-26.*HSCA  -1.5)
      UCMCON=DCA*(0.01+0.23*HSCA)
      IF(HSCA  .GE.0.) GO TO 1200
      UCECON=DCA*(SQRT(RMLMAX+40.)+6.*HSCA  -1.5)
      UCMCON=0.01*DCA
C     COST OF MUCK TRANSFER IN AIR LOCK
 1200 UCEMT=8.10
      IF(RMLMAX.LE.100.) UCEMT=4.50
      IF(RMLMAX.GT.300.) UCEMT=14.9
      UCMMT=0.02
      UCL=((0.013*AR+0.6*DCA)*SQRT(RMLMAX+40.)+0.06*AR-1.1*DCA)*CFLCA
     1   +7.7*(TRUCKS+CFLCA)+23.9+CLIND*AR/HOURS
      UCE=UCECON+UCEMT+UCETR
      UCM=UCMCON+UCMMT+UCMTR
C     ------------------------------------------------------------------
C     CALCULATE MUCK TRANSPORT COSTS
C     ----------------------------------------
  400 CLMT=UCL*HOURS*CFLWWK/AR
      CEMT=UCE*HOURS/AR*CFEWWK
      CMMT=UCM*V
      IF(HH.GT.0.) GO TO 500
C     SHAFT IS A PORTAL, HOISTING COSTS ARE ZERO
  300 UCL=0.
      UCE=0.
      UCM=0.
      UCLIND=0.
      GO TO 700
C     COST OF BACKFILL TRANSPORT IN CUT AND COVER
 2000 DCENT=(DCENT*VSOIL-VBOX*(DTRNCH-TOTBOX/2.))/(V-VBOX)
      IF(DROCK.LT.DTRNCH) DCENT=DCENT+VROCK*(DTRNCH+DROCK)/2./(V-VBOX)
      TRUCKS=(0.02+(OPEN+DCENT/0.1)/75000.)*VBACEX*(V-VBOX)*AR/HOURS
      IF(TRUCKS.LT.1.) TRUCKS=1
      UCL=(10.+(15.5+4.7*DDS)*VBACDS*(V-VBOX)*AR/1000.)*24./HOURS
     1   +8.20+6.25*TRUCKS
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(Continued)

```
      UCE=(6.+(12.5+2.1*DDS)*VBACDS*(V-VBOX)*AR/1000.)*24./HOURS
     1   +8.40+2.70*TRUCKS
      UCM=0.055*DDS*VBACDS+0.00005*(OPEN+DCENT/0.1)*VBACEX
     1   +8.2*HOURS/AR/(V-VBOX)
C     CALCULATE COST OF BACKFILL TRANSPORT PER FOOT OF TUNNEL
      CLMT=UCL*HOURS/AR*CFLWWK
      CEMT=UCE*HOURS/AR*CFEWWK
      CMMT=UCM*(V-VBOX)
C     RESET UNIT COSTS TO ZERO SO MUCK HOISTING COST WILL BE ZERO IN
C     CUT-AND-COVER
      GO TO 300
C     ****************************************************************
C     CALCULATE UNIT COST OF MUCK HOISTING IN TUNNELS
  500 UCL=35.+0.003*HH*(1.+0.002*RMLMAX)+0.016*RMLMAX
      UCE=10. + 0.03*RMLMAX
      UCM=0.05
      UCLIND=(50000.+0.04*(900.+HH)*RMLMAX)/RL
      GO TO 700
C     ----------------------------------------------------------------
C     CALCULATE UNIT COST OF MUCK HOISTING IN SHAFTS
  600 UCL=0.
      UCE=0.
      UCM=0.
      UCLIND=0.
      IF(NSTYP.EQ.3) GO TO 800
      UCL=29. + 0.002*HH*(1.+0.008*RMLMAX)
      UCE=3.+0.04*RMLMAX
      UCM=0.05
      UCLIND=0.
C     ----------------------------------------------------------------
C     CALCULATE MUCK HOISTING COSTS
  700 CLMH=(HOURS*UCL/AR+UCLIND)*CFLWWK
      CEMH=HOURS*UCE/AR*CFEWWK
      CMMH=UCM*V*HH/1000.
      GO TO 750
  800 CLMH=0.
      CEMH=0.
      CMMH=0
  750 CONTINUE
C     STORE COST VALUES FOR USE IN LINING COMPUTATION
      UCLMH=UCL
      UCEMH=UCE
C
      RETURN
      END
      SUBROUTINE CMUKDP(CLMD,CEMD,CMMD,AR,V,CDS,DDS,VDS,NSTYP,HOURS,
     1                  CFLWWK,CFEWWK,ITYPE)
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C     CMUKDP CALCULATES THE COST OF MUCK DISPOSAL FOR TUNNELS AND SHAFTS
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
      IF(ITYPE.EQ.2.AND.NSTYP.EQ.3) GO TO 100
C
C     CALCULATE UNIT COST OF MUCK DISPOSAL
      VMKDP=V
```

(Continued)

```
      IF (NSTYP.EQ.3) UMKDP=UDS*U
      UCL=(10.+(15.5+4.7*DDS)*UMKDP*AR/1000.)*24./HOURS
      UCE=(8.+(12.5+2.10*DDS)*UMKDP*AR/1000.)*24./HOURS
      UCM=0.055*DDS
      UCDS=CDS*UMKDP*0.00003
C     CALCULATE COST OF MUCK DISPOSAL
      CLMD=UCL*HOURS/AR*CFLWUK
      CEMD=UCE*HOURS/AR*CFEWUK
      CMMD=UCDS+UCM*UMKDP
      GO TO 200
C
  100 CLMD=0.
      CEMD=0.
      CMMD=0.
C
  200 RETURN
      END
      SUBROUTINE CTSUP(CLTS,CETS,CMTS,RQD,MEX,ISHAPE,BE,AR,RS,BE40,BE60
     1,ITYPE,Y,DM,NSTYP,BF,ISUPPT,TPLATE,TSEG,PSOIL,WEB,PTOTAL,
     2BOB,LINWT,MSTAB,CFLCA,HOURS,CFLWUK,CFEWUK,DSLURY,DTRNCH,IDECK,
     3DROCK,WTSTRT,WTWALE,SPDLT,WTSPD,WTSP,WTANCH,TOTBOX,IBRACE,SFA)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CTSUP CALCULATES THE COST OF SUPPORTS IN TUNNELS AND SHAFTS
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     IS IT A ROCK TUNNEL OR SHAFT
      IF(NSTYP.EQ.1) GO TO 5
C     II IS A FLOW INDICATOR
      II=4
C     IS IT A SOFT GROUND TUNNEL OR SHAFT
      IF(NSTYP.EQ.2) GO TO 1000
      GO TO 1500
C
C     ******************************************************************
C     ROCK TUNNELS AND SHAFTS
C     ******************************************************************
C
    5 IF(ITYPE.EQ.2) ISHAPE=1
      E=2.71828
      IF(RQD.GT.40..AND.RQD.LT.60.) GO TO 10
      IF(RQD.LE.40.) GO TO 40
C     RQD .GE. 60    ROCK BOLTS USED
   20 II=4
  510 GO TO (200,210),MEX
C     CONVENTIONAL EXCAVATION
  200 IF(ISHAPE.LT.3) GO TO 220
C     ------------------------------------------------------------------
C     F IS A ROCK BOLT WEIGHT FACTOR, FF IS A WIRE MESH WEIGHT FACTOR
C     SHAPE IS BASKETHANDLE
      F=1.6
      FF=0.74
      GO TO 230
C     SHAPE IS CIRCLE OR HORSESHOE
  220 F=1.0
      FF=1.0
      GO TO 230
C     MOLE EXCAVATION
```

(Continued)

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  210 F=0.56
      FF=1.0
C     CALCULATE WEIGHT OF ROCK BOLTS
  230 URB=(F*8.56*BE*E**(0.026*BE)*(100-RQD)**2)/(152.-RQD)**2
      GO TO(240,250),ITYPE
C     CALCULATE WEIGHT OF WIRE MESH IN TUNNELS
  240 WWM=FF*3.3*BE*(1.-0.01*RQD)
C     ------------------------------------------------------------------
C     UNIT COSTS OF ROCK BOLT SUPPORTS IN TUNNELS
      UCL=0.02*URB*AR
      IF(BE.LE.16.) UCE=1.76
      IF(BE.GT.16..AND.URB*AR.LE.1000.) UCE=9.35
      IF(BE.GT.16..AND.URB*AR.GT.1000.) UCE=9.35+0.0023*(URB*AR-1000.)
      UCM=0.32*WWM+(0.23+RS/530000.)*URB
      GO TO 300
C     ------------------------------------------------------------------
C     WEIGHT OF WIRE MESH IN SHAFTS
  250 WWM=FF*4.*BE
C     ------------------------------------------------------------------
C     UNIT COSTS OF ROCK BOLT SUPPORTS IN SHAFTS
      UCL=0.0
      IF(MEX.EQ.1) UCE=0.0
      IF(MEX.EQ.2) UCE=1.76
      UCM=0.32*WWM+(0.23+RS/530000.)*URB
      GO TO 300
C     ------------------------------------------------------------------
C     RQD IS BETWEEN 40 AND 60,INTERPOLATION OF COSTS IS NECESSARY.
C     COST WILL BE COMPUTED FOR RQD=40 AND THEN FOR RQD=60 BEFORE
C     INTERPOLATING TO OBTAIN COSTS AT ACTUAL RQD.
C
C     STORE THE CORRECT VALUES OF RQD AND BE
   10 RQDD=RQD
      BBE=BE
C     ESTABLISH FICTITIOUS VALUES OF RQD AND SIZE FOR INTERPOLATION USE
      BE=BE40
      RQD=40
      II=1
      GO TO 410
C     RQD .LE. 40   STEEL SETS USED
   40 II=4
  410 GO TO (420,430,440),ISHAPE
C     SHAPE IS CIRCLE
  420 GO TO (450,460),MEX
C     ------------------------------------------------------------------
C     FACTOR FOR WEIGHT OF STEEL SUPPORTS=F
C     CONVENTIONAL EXCAVATION
  450 F=0.56*((RQD-20.)/100.)**2+1.22
C     FBL=  FACTOR FOR BLOCKING AND LAGGING
      FBL=1.0
      GO TO 470
C     MOLE EXCAVATION
  460 F=1.0
      FBL=0.81
C     WEIGHT OF STEEL SUPPORTS
  470 WST=F*E**(SQRT(ABS(0.7*BE-6.))+3.7-2*((RQD+20.)/100.)**2)
      GO TO 480
C     SHAPE IS HORSESHOE
  430 WST=E**(SQRT(ABS(0.85*BE-7.))+0.8+0.3*SQRT(100.-RQD))
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(Continued)

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      FBL=1.+0.012*BE
      GO TO 480
C     SHAPE IS BASKETHANDLE
  440 WST=E**(SQRT(ABS(0.92*BE-6.))+0.82+0.22*SQRT(100.-RQD))
      FBL=1.+0.003*BE
C     QUANTITY OF BLOCKING AND LAGGING
  480 BL=FBL*BE*(0.0018+0.0056*((117.-RQD)/100.)**2)
      GO TO (490,500),ITYPE
C     ------------------------------------------------------------------
C     UNIT COSTS OF STEEL SUPPORTS IN TUNNELS
  490 IF(MEX.EQ.1) YY=1.1
      IF(MEX.EQ.2) YY=1.0
      UCL=YY*(0.001*WST*AR+0.4*BE)
      UCE=YY*(6.+0.0002*WST*AR)
      UCM=36.*YY/AR+0.095*WST+150.*BL
      GO TO 300
C     ------------------------------------------------------------------
C     UNIT COSTS OF STEEL SUPPORTS IN SHAFT
  500 UCL=1.1/3.*(0.001*WST*AR+0.4*BE)
      UCE=1.1/3.*(6.+0.0002*WST*AR)
      UCM=0.095*WST+150.*BL
C     ------------------------------------------------------------------
C     COST OF SUPPORTS
C
  300 CLTS=(HOURS*CFLWWK+Y*DM)*UCL/AR
      CETS=HOURS*CFEWWK*UCE/AR
      CMTS=UCM
C     ------------------------------------------------------------------
      IF(II.GE.3) GO TO 700
      IF(II.GE.2) GO TO 600
C     STORE COSTS COMPUTED USING FICTITIOUS RQD=40
      CL40=CLTS
      CE40=CETS
      CM40=CMTS
C     REDEFINE RQD TO A FICTITIOUS VALUE OF 60 FOR SECOND PART OF
C     INTERPOLATION COMPUTATION
      RQD=60
      BE=BE60
C     REDEFINE FLOW INDICATOR
      II=II+1
      GO TO 510
C     STORE COSTS COMPUTED USING FICTITIOUS RQD=60
  600 CL60=CLTS
      CE60=CETS
      CM60=CMTS
C     ------------------------------------------------------------------
C     INTERPOLATE BETWEEN RQD OF 40 AND 60 TO OBTAIN SUPPORT COSTS
      CLTS=CL40+((RQDD-40)/20)*(CL60-CL40)
      CETS=CE40+((RQDD-40)/20)*(CE60-CE40)
      CMTS=CM40+((RQDD-40)/20)*(CM60-CM40)
C     ------------------------------------------------------------------
C     REINSTATE ORIGINAL VALUES OF RQD AND BE
      RQD=RQDD
      BE=BBE
  700 RETURN
```

(Continued)

```
C
C     ****************************************************************
C     SOFT GROUND TUNNELS OR SHAFTS
C     ****************************************************************
C
C     ESTABLISH SHAPE FACTOR BASED ON PERIMETER
 1000 IF(ITYPE.EQ.2) GO TO 1035
      GO TO(1010,1020,1030 ),ISHAPE
C     CIRCULAR
 1010 SFP=3.14
      GO TO 1050
C     HORSESHOE
 1020 SFP=3.57
      GO TO 1050
C     BASKETHANDLE
 1030 SFP=2.66
      GO TO 1050
C     SHAFT SEGMENT
 1035 IF(ISHAPE.EQ.1) GO TO 1010
C     SQUARE
      SFP=4
 1050 PERMTR=0.5*(BE+BF)*SFP
      GO TO(1060,1070,1060,1300),ISUPPT
C     SEGMENTED CAST IRON OR STEEL SUPPORTS
 1060 S=3
      GO TO 1080
C     SEGMENTED CONCRETE SUPPORTS
 1070 S=4
 1080 TWEB=TPLATE
      IF(TWEB.GT.1.) TWEB=1
      AREA=S*TPLATE+2.*TWEB*(TSEG-TPLATE)
C     CALCULATE SUPPORT QUANTITIES
      GO TO(1110,1120,1190),ISUPPT
C     ----------------------------------------------------------------
C     SEGMENTED CAST IRON SUPPORTS
 1110 WCI=450.*(AREA+0.667*(S-2.*TWEB)*(TSEG-TPLATE)*TWEB)/S*PERMTR
      YY=0.13*WCI
      GO TO 1200
C     ----------------------------------------------------------------
C     SEGMENTED CONCRETE SUPPORTS
 1120 VL=1./27.*(AREA+0.667*(S-2.*TWEB)*(TSEG-TPLATE)*TWEB)/S*PERMTR
      IF(ITYPE.EQ.2) GO TO 1175
C     TUNNEL SEGMENT
      GO TO (1150,1160,1170),ISHAPE
C     CIRCULAR
 1150 RST=0.01
      GO TO 1185
C     HORSESHOE
 1160 RST=0.032-0.16E-6*PTOTAL
      PMINT=54000./BF**1.5
      RSTMNT=0.032-0.16E-6*PMINT
      GO TO 1180
C     BASKETHANDLE
 1170 RST=0.032-0.16E-6*PTOTAL
      PMINT=60000./BF**1.7
```

(Continued)

```
      RSTMNT=0.032-0.16E-6*PMINT
      GO TO 1180
C     SHAFT SEGMENT
 1175 IF(ISHAPE.EQ.1) GO TO 1150
C     SQUARE
      RST=0.034-0.13E-6*PTOTAL
      PMINT=50000./BF**1.9
      RSTMNT=0.034-0.13E-6*PMINT
 1180 IF(PTOTAL.LT.PMINT) RST=0.01+(RSTMNT-0.01)/PMINT*PTOTAL
      IF(RST.LT.0.01) RST=0.01
 1185 WREIN=491.*RST*UL*27.
      YY=99.*UL+0.15*WREIN
      GO TO 1200
C     ------------------------------------------------------------------
C     SEGMENTED STEEL SUPPORTS
 1190 UST=491.*(AREA+0.667*(S-2.*TWEB)*(TSEG-TPLATE)*TWEB)/S*PERMTR
      YY=0.095*UST
 1200 IF(ITYPE.EQ.2) GO TO 1210
C     TUNNEL SEGMENT
      Y3=1
      GO TO 1230
C     SHAFT SEGMENT
C     IS COMPRESSED AIR USED
 1210 IF(MSTAB.EQ.1) GO TO 1220
      Y3=0.333
      GO TO 1230
 1220 Y3=1.25
 1230 UCL=Y3*(50.+0.04*BE**2)*((CFLCA-1.)*2./3.+1.)
      IF(ITYPE.EQ.2) UCL=Y3*(50.+0.04*BE**2)
      UCE=Y3*(5.5+0.003*(BE+10.)**2)
      UCM=Y3*(2.1+0.001*BE**2)*HOURS/AR+YY
C     ------------------------------------------------------------------
C     ADD COST FOR CAULKING SEGMENTED SUPPORTS IN WATERTIGHT TUNNELS
C     AND SHAFTS
      IF(LINWT.EQ.1) GO TO 1240
      GO TO 1350
 1240 IF(ITYPE.EQ.2) GO TO 1250
C     TUNNEL SEGMENT
      IF(ISHAPE.EQ.1) GO TO 1260
C     HORSESHOE OR BASKETHANDLE
      SEGN=6
      GO TO 1270
 1250 IF(ISHAPE.EQ.1) GO TO 1260
C     SQUARE
      SEGN=8
      GO TO 1270
```

(Continued)

```
      GO TO 1270
C     CIRCULAR
 1260 SEGN=3
 1270 CJOINT=BE*SFP/S+SEGN
      IF(ITYPE.EQ.1) UCL=UCL+0.175*CJOINT*AR*CFLCA/HOURS
      IF(ITYPE.EQ.2) UCL=UCL+0.175*CJOINT*AR/HOURS
      UCE=UCE+0.025*CJOINT*AR/HOURS
      UCM=UCM+0.3*CJOINT
      GO TO 1350
C     ---------------------------------------------------------------
C     STEEL RIB SUPPORT
 1300 S=10.-0.65*ALOG(PSOIL)
      IF(S.GT.6.) S=6
      AREA=1./144.*EXP(4.26*SQRT (WEB-0.33))
      WST=491.*AREA*SFP*(BE-WEB)/S
      BLTHCK=1./535.*SQRT(PSOIL)*(9.5-0.65*ALOG(PSOIL))
C     ASSUME MINIMUM LAGGING THICKNESS TO BE 5 INCHES
      IF(BLTHCK.LT.5./12.)BLTHCK=5./12.
      BL=BLTHCK*12.*SFP*(BE-BLTHCK)/1000.
      IF(ITYPE.EQ.2) GO TO 1320
C     TUNNEL SEGMENT
      YY=1.1
      Y3=39.6
      GO TO 1340
C     SHAFT SEGMENT
C     IS COMPRESSED AIR USED
 1320 IF(MSTAB.EQ.1) GO TO 1330
      YY=1.1/3.
      Y3=0
      GO TO 1340
 1330 YY=1.4
      Y3=50
 1340 UCL=YY*(0.001*WST*AR+0.4*BE)*((CFLCA-1.)*2./3.+1.)
      IF(ITYPE.EQ.2) UCL=YY*(0.001*WST*AR+0.4*BE)
      UCE=YY*(6.+0.0002*WST*AR)
      UCM=Y3/AR+0.095*WST+150.*BL
C     ADD COST FOR BACKFILL GROUT
 1350 VBACKG=SFA*(BOB**2-BE**2)
      IF(ITYPE.EQ.1) UCL=UCL+1.3*VBACKG*AR*CFLCA/HOURS
      IF(ITYPE.EQ.2) UCL=UCL+1.3*VBACKG*AR/HOURS
      UCE=UCE+0.5*VBACKG*AR/HOURS
      UCM=UCM+1.2*VBACKG
      GO TO 300
C
C     ****************************************************************
C     CUT AND COVER
C     ****************************************************************
C     SET COSTS=0
 1500 UCL=0
      UCE=0
      UCM=0
C     IS IT A SHAFT
      IF(ITYPE.EQ.1) GO TO 1505
      CLTS=0.
      CETS=0.
```

(Continued)

```
      CMTS=0.
      RETURN
C     FOR SLOPING CUT, ONLY COST OF ROCK BOLTS WILL BE COMPUTED
 1505 IF(MEX.EQ.7) GO TO 1750
C     IF OPEN CUT IS ENTIRELY IN ROCK, ONLY COST OF ROCK BOLTS IS
C     COMPUTED FOR SUPPORTS
      IF(DROCK.LT.0.1) GO TO 1760
      DROOF=DTRNCH-TOTBOX
      IF(ISUPPT.EQ.6) GO TO 1510
      GO TO 1515
C     ------------------------------------------------------------------
C     SLURRY WALL
C     ------------------------------------------------------------------
 1510 IF(DROCK.LE.DROOF-2.) SLURRY=0.5*DROCK/12.
      IF(DROCK.GT.DROOF-2.) SLURRY=0.5*DTRNCH/12.
      IF(SLURRY.LT.1.5) SLURRY=1.5
      UCL=UCL+145.*DSLURY*SLURRY/2600.*AR/HOURS
      UCE=UCE+181.*DSLURY*SLURRY/2600.*AR/HOURS
      UCM=UCM+(1.4*SLURRY-0.6)*DTRNCH*1.15
C     ------------------------------------------------------------------
C     WALES AND STRUTS
C     ------------------------------------------------------------------
C     WALERS AND STRUTS ARE SPACED 10 FEET VERTICALLY.
C     ACTUAL NUMBER OF STRUTS AND WALERS REQUIRED IS DSOIL/10 - 1
C     BECAUSE RESTRAINT AT BOTTOM OF SOLDIER PILE ACTS AS A STRUT.
C     IF ACTUAL NUMBER REQUIRED IS LESS THAN ONE, THEN USE ONE.
C     IS ROCK LINE ABOVE TRENCH BOTTOM
 1515 IF(DROCK.LT.DTRNCH) GO TO 1520
      STRUT=(DTRNCH/10.-1.)/15.*BE*WTSTRT
      IF(IBRACE.EQ.3) STRUT=(DROOF/10.-1.)/15.*BE*WTSTRT
      WALE=(DTRNCH/10.-1.)*2.*WTWALE
      GO TO 1560
 1520 STRUT=(DROCK/10.-1.)/15.*BE*WTSTRT
      IF(IBRACE.EQ.3 .AND. DROOF.LT.DROCK) STRUT=(DROOF/10.-1.)/15.*
     1BE*WTSTRT
C     IS DECKING REQUIRED
      IF(IDECK.EQ.1) GO TO 1540
      WALE=(DROCK/10.-1.)*2.*WTWALE
      GO TO 1560
 1540 WALE=(DROCK/10.-1.)*2.*WTWALE+((DTRNCH-DROCK)/10.-1.)*2.*13.
C     VERTICAL CUTS IN SOIL LESS THAN 20 FEET HAVE ONE STRUT
 1560 IF(STRUT.LT.BE*WTSTRT/15.) STRUT=BE*WTSTRT/15.
C     THERE ARE TWO WALES FOR EVERY STRUT AND A MINIMUM OF TWO WALES
C     CONNECTING DECKED SOLDIER PILES IN ROCK
      IF(IDECK.EQ.1.AND.DROCK.LT.DTRNCH.AND.WALE.LT.2.*WTWALE+26.)
     1 WALE=2.*WTWALE+26.
      IF(WALE.LT.2.*WTWALE) WALE=2.*WTWALE
```

(Continued)

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C      NO STRUTS IF COMPLETELY SUPPORTED BY ANCHORS
       IF(IBRACE.EQ.2) STRUT=0
C      NO WALES FOR SLURRY WALL
       IF(ISUPPT.EQ.6) WALE=0
C      NO COSTS OF WALES AND STRUTS FOR SLURRY WALL SUPPORTED BY ANCHORS
       IF(ISUPPT.EQ.6 .AND. IBRACE.EQ.2) GO TO 1570
       UCL=UCL+46.+1.3*SQRT(WALE+STRUT)
       UCE=UCE+16.+0.45*SQRT(WALE+STRUT)
       UCM=UCM+0.095*WALE+0.24*STRUT
C      ------------------------------------------------------------
C      ADD COST OF SOLDIER PILES
C      ------------------------------------------------------------
 1570  IF(ISUPPT.EQ.6) GO TO 1605
       IF(DROCK.LT.DTRNCH) GO TO 1580
       SPLT=DTRNCH+10.
       GO TO 1600
 1580  SPLT=DROCK+10.
 1600  IF(IDECK.EQ.0) SPDLT=SPLT
       IF(IDECK.EQ.0) WTSPD=WTSP
       GO TO 1610
C      SOLDIER PILES EMBEDED IN SLURRY WALL
 1605  SPLT=DSLURY
       SPDLT=DSLURY
       WTSP=13
       WTSPD=13
 1610  PILE=(2.*SPLT*WTSP+SPDLT*WTSPD)*2./15.
       DWTAVG=SQRT(6. *(2.*WTSP*SPLT+WTSPD*SPDLT)/(2.*SPLT+SPDLT))
       SPLTAV=(2.*SPLT+SPDLT)/3.
       UCL=UCL+(0.009*(DWTAVG+7.)**2-0.2)*0.4*SPLTAV*AR/HOURS
       UCE=UCE+0.02*DWTAVG*SPLTAV*AR/HOURS
       UCM=UCM+0.012*DWTAVG*SPLTAV+0.1*PILE
C      ------------------------------------------------------------
C      ADD COST OF LAGGING
C      ------------------------------------------------------------
C      NO LAGGING FOR SLURRY WALL
       IF(ISUPPT.EQ.6) GO TO 1710
       IF(DROCK.LT.DTRNCH) GO TO 1660
       IF(DTRNCH.GT.25.) GO TO 1640
       BL=DTRNCH*3.*2./1000.
       GO TO 1700
 1640  BL=(25.*3.+(DTRNCH-25.)*4.)*2./1000.
       GO TO 1700
 1660  IF(DROCK.GT.25.) GO TO 1680
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(Continued)

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      BL=DROCK*3.*2./1000.
      GO TO 1700
 1680 BL=(25.*3.+(DROCK-25.)*4)*2./1000.
 1700 UCL=UCL+53.*AR*BL/HOURS/0.6
      UCE=UCE+1.4
      UCM=UCM+20.*BL
C     ------------------------------------------------------------
C     ADD COST OF TIEBACK ANCHORS
C     ------------------------------------------------------------
C     NO TIEBACK ANCHORS IF COMPLETELY SUPPORTED BY STRUTS
 1710 IF(IBRACE.EQ.1) GO TO 1750
      IF(DROCK.LT.DTRNCH) GO TO 1720
      ANCHLT=0.3*DTRNCH+20.
      DSOIL=DTRNCH
C     Y1=PORTION SUPPORTED BY TIEBACK ANCHORS
      Y1=1
      IF(IBRACE.EQ.3) Y1=TOTBOX/DTRNCH
      GO TO 1740
 1720 ANCHLT=0.3*DROCK+20.
      DSOIL=DROCK
C     Y1=PORTION SUPPORTED BY ANCHORS
      IF(IBRACE.EQ.3 .AND. DROCK.LT.DROOF) Y1=1
      IF(IBRACE.EQ.3 .AND. DROCK.GT.DROOF) Y1=(DROCK-DROOF)/DROCK
 1740 ANCHDI=SQRT(WTANCH/2.67)
      GRTAKE=1.88*DSOIL
      VBF=(ANCHLT-20.)*0.785*(1-(ANCHDI/12.)**2)/27.*0.04*DSOIL
      UCLAN=3.*ANCHLT*DSOIL *AR/HOURS/(10.-80./ANCHLT)*Y1
      IF(UCLAN.LT.75.) UCLAN=75
      UCEAN=0.7*ANCHLT*DSOIL *AR/HOURS/(10.-80./ANCHLT)*Y1
      IF(UCEAN.LT.17.5) UCEAN=17.5
      UCMAN=(ANCHDI**2*(0.8-0.003*ANCHLT)*0.04*ANCHLT*DSOIL +80.*GRTAKE
     1  /27.+6.75*VBF)*Y1
      UCL=UCL+UCLAN
      UCE=UCE+UCEAN
      UCM=UCM+UCMAN
C     ------------------------------------------------------------
C     ADD COST OF ROCK BOLTS
C     ------------------------------------------------------------
 1750 IF(DROCK.LT.DTRNCH) GO TO 1760
      GO TO 1800
 1760 ANCHLT=0.25*(DTRNCH-DROCK)+250./RQD
      UCLRB=110.*ANCHLT*(DTRNCH-DROCK)*AR/HOURS/(1.2+130./(110.-RQD))**2
     1/(50.-0.25*ANCHLT)
      IF(UCLRB.LT.54.) UCLRB=54.
      UCERB=20.*ANCHLT*(DTRNCH-DROCK)*AR/HOURS/(1.2+130./(110.-RQD))**2
     1/(50.-0.25*ANCHLT)
      IF(UCERB.LT.10.) UCERB=10
      UCMRB=1.5*ANCHLT*(DTRNCH-DROCK)/(1.2+130./(110.-RQD))**2
      UCL=UCL+UCLRB
      UCE=UCE+UCERB
      UCM=UCM+UCMRB
 1800 IF(MEX.EQ.7) GO TO 300
C     ------------------------------------------------------------
C     DECKING
C     ------------------------------------------------------------
C     IS DECKING REQUIRED
      IF(IDECK.EQ.1) GO TO 1820
      GO TO 300
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(Continued)

```
C     ADD COST OF TIMBER
 1820 UCL=UCL+0.078*BE*AR/HOURS
      UCE=UCE+0.009*BE*AR/HOURS
      UCM=UCM+0.18*BE
C     ADD COST OF GIRDERS AND STRINGERS
      UCL=UCL+15.+(5.3*BE+520.)**2/40000.
      UCE=UCE+6.5+7.*(BE+100.)**2/10000.
      UCM=UCM+0.16*(5.3*BE+30.)
      GO TO 300
      END
      SUBROUTINE LINING1(CLL,CEL,CML,CLFW,CEFW,CMFW,ITYPE,LINING,RQD,MEX
     1,WEB,TL,BOB,BOB40,BF,Y,DM,BOB60,ISHAPE,BE,UCLT,UCET,MTM,
     2UCLMH,UCEMH,SFA,NOFORM,AR,NSTYP,PSOIL,PWATER,VL,SFP,
     3FORMAR,HOURS,CFLCA,CFLWWK,CFEWWK)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     LINING CALCULATES THE LINING COSTS AND THE FORMWORK COST FOR A
C     TUNNEL OR SHAFT SEGMENT
C     ------------------------------------------------------------------
      IF(NSTYP.EQ.3) GO TO 910
C     *******************    ROCK OR SOFT GROUND    *********************
C     II IS A FLOW INDICATOR
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
C     IS SEGMENT LINED
      IF(LINING.GT.0) GO TO 37
C     SEGMENT IS UNLINED --- SET ALL COSTS TO ZERO
      CLL=0.0
      CEL=0.0
      CML=0.0
    2 CLFW=0.0
      CEFW=0.0
      CMFW=0.0
      RETURN
C
C
C     ------------------------------------------------------------------
C     RATIO OF REINFORCEMENT TO CONCRETE BY VOLUME
C     ------------------------------------------------------------------
C     SET MINIMUM STEEL REQUIREMENTS
   37 IF(NSTYP.EQ.1) RSTMIN=0.005
      IF(NSTYP.EQ.2) RSTMIN=0.01
      IF(ITYPE.EQ.2) GO TO 49
C     TUNNEL SEGMENT
      GO TO(41,42,45),ISHAPE
C     CIRCLE
   41 RST=RSTMIN
      GO TO 4
C     HORSESHOE
   42 RST=0.014-7.3E-8*PWATER
      IF(LINING.EQ.1) PMINT=195000/BF**1.7
      IF(LINING.EQ.2) PMINT=36500/BF**1.6
   44 RSTMNT=0.014-7.3E-8*PMINT
      GO TO 48
C     BASKETHANDLE
   45 RST=0.014-6.6E-8*PWATER
      IF(LINING.EQ.1) PMINT=280000/BF**1.9
```

(Continued)

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   40 IF(LINING.EQ.2) PMINT=56000/BF**1.8
   47 RSTMNT=0.014-6.6E-8*PMINT
      GO TO 48
C     SHAFT SEGMENT
C     IS IT CIRCULAR SHAPE
   49 IF(ISHAPE.EQ.1) GO TO 41
      RST=0.015-6.25E-8*PWATER
      IF(LINING.EQ.1) PMINT=175000/BF**1.9
   50 IF(LINING.EQ.2) PMINT=31000/BF**1.8
   51 RSTMNT=0.015-6.25E-8*PMINT
   48 IF(PWATER.LE.PMINT) RST=RSTMIN+(RSTMNT-RSTMIN)*PWATER/PMINT
      IF(RST.LT.RSTMIN) RST=RSTMIN
C     ------------------------------------------------------------------
C     IS IT A SOFT GROUND TUNNEL OR SHAFT
    4 IF(NSTYP.EQ.2) GO TO 40
C     ROCK TUNNELS OR SHAFTS
C     CHECK RQD
    5 IF(RQD.LE.40.) GO TO 40
      IF(RQD.GE.60.) GO TO 20
C     RQD IS BETWEEN 40 AND 60,INTERPOLATION OF COSTS IS NECESSARY.
C     COST WILL BE COMPUTED FOR RQD=40 AND THEN FOR RQD=60 BEFORE
C     INTERPOLATING TO OBTAIN COSTS AT ACTUAL RQD.
   10 II=1
C     STORE THE CORRECT VALUES OF RQD AND BOB
      RQDD=RQD
      BBOB=BOB
C     ESTABLISH FICTITIOUS VALUES OF RQD AND SIZE FOR INTERPOLATION USE
      RQD=40.
      BOB=BOB40
      GO TO 55
C     RQD .GE. 60
   20 II=4
   30 F=1.
      GO TO (200,300),LINING
C     RQD .LE. 40
   40 II=4.
   55 IF(LINING.EQ.1) GO TO 200
C     IS THIS A SOFT GROUND TUNNEL OR SHAFT
      IF(NSTYP.EQ.2) GO TO 300
      S=0.05*RQD+1.25
C     TL IS STORED IN FEET
   59 IF(     TL.LT.WEB) GO TO 70
C     F IS A FACTOR FOR INCREASING SHOTCRETE VOLUME OVER STEEL SETS
   60 F=1.
      GO TO 300
   70 F=(S+WEB/4.)/S
      GO TO 300
C
C     ******************************************************************
C     CONCRETE LINING
C     ------------------------------------------------------------------
  200 VL=SFA/27.*(BOB**2-BF**2)
      VLREIN=SFA/27.*(BE**2.-BF**2.)
      IF(NSTYP.EQ.2) VL=4./27.*SFA*TL*(BF+TL)
      IF(NSTYP.EQ.2) VLREIN=VL
      WREIN=491.*RST*VLREIN*27.
      GO TO(220,260),ITYPE
  220 IF(NSTYP.EQ.2) GO TO 230
```

(Continued)

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C     ------------------------------------------------
C     UNIT COST OF LINING MATERIAL TRANSPORT IN TUNNELS ONLY
      GO TO (221,225,223,221),MTM
C     TRUCK TRANSPORT,      Z=TRUCK VOLUME/4
  221 IF(ISHAPE.LE.2) Z=5.-0.001*(70.-BE)**2
      IF(ISHAPE.EQ.3) Z=4.5-(BE-50.)**4/44000.
      TRUCKS=(0.28*DM+0.48)*VL/Z
      IF(TRUCKS.LT.1.0) TRUCKS=1.
      UCLT=7.7*TRUCKS+7.1
      UCET=(1.5+3.1*Z)*TRUCKS
      GO TO 226
C     RAIL TRANSPORT
  223 CARS=(0.42*DM+1.5)*VL
      IF(CARS.LT.1.0) CARS=1.0
      ENGINE=CARS/10.
      IF(ENGINE.LT.1.0) ENGINE=1.
      UCLT=15.*ENGINE+21.*DM**0.82
      UCET=5.8*ENGINE+CARS+1.4*DM
      GO TO 226
  225 CONTINUE
C     CONVEYOR -- UCET AND UCLT WERE COMPUTED IN SUBROUTINE CMTAH
  226 AL=3.*HOURS
      GO TO 240
  230 UCLT=0
      UCET=0
      UCEMH=0
      AL=AR
C     UNIT COSTS OF LINING IN TUNNEL
  240 UCL=(0.0018*(VL*AL/HOURS+160.)**2-12.+UCLT)*CFLCA
      UCE=5.+0.3*VL*AL/HOURS+UCET+UCEMH
      UCM=13.+0.15*UREIN/VL
      GO TO 400
C     ------------------------------------------------
C     UNIT COST OF SHAFT LINING
  260 UCL= 25.+3.0*VL+UCLMH
      UCE=7.+0.40*VL+UCEMH
      UCM=13.+0.15*UREIN/VL
      AL=2.*HOURS
      GO TO 400
C     *****************************************************************
C
C     SHOTCRETE LINING
  300 VL=4.*SFA/27.*TL*F*(BOB-TL)
      IF(NSTYP.EQ.2) VL=4./27.*SFA*TL*(BF+TL)
      VLREIN=VL
      AL=AR
      UREIN=491.*RST*VLREIN*27.
C     ------------------------------------------------
C     COST OF LINING MATERIAL TRANSPORT IN SHOTCRETED TUNNELS IS
C     INCLUDED IN MUCK TRANSPORT AND HOISTING COSTS.
C     CALCULATE UNIT COSTS OF TUNNEL AND SHAFT LINING
      UCL=(0.036*(VL*AL/HOURS+40.)**2.+10.)*CFLCA
      IF(ITYPE.EQ.2) UCL=0.035*(VL*AL/HOURS+40.)**2+10.
      UCE=0.004*(VL*AL/HOURS+100.)**2.-23.
      UCM=14.+0.15*UREIN/VL
C     *****************************************************************
C
  400 CONTINUE
```

(Continued)

```
C      CALCULATE LINING COSTS
       IF(LINING.EQ.2) UCLMH=0.
       IF(ITYPE.EQ.1)CLL=(HOURS*CFLUWK+Y*DM)/AL*UCL+HOURS*CFLUWK*UCLMH/AL
       IF(ITYPE.EQ.2) CLL=HOURS*UCL*CFLUWK/AL
       CEL=HOURS*CFEUWK*UCE/AL
       CML=UL*UCM
C      ---------------------------------------
       IF(II.GE.3) GO TO 525
       IF(II.GE.2) GO TO 500
C      STORE LINING COSTS COMPUTED USING FICTITIOUS RQD=40
       CL40=CLL
       CE40=CEL
       CM40=CML
C      REDEFINE RQD TO A FICTITIOUS VALUE OF 60 FOR SECOND PART OF
C      INTERPOLATION COMPUTATION
       RQD=60
       BOB=BOB60
C      REDEFINE FLOW INDICATOR
       II=II+1
       GO TO 30
C      ------------------------------------------------------------------
C
C      STORE LINING COSTS COMPUTED USING FICTITIOUS RQD=60
  500  CL60=CLL
       CE60=CEL
       CM60=CML
C      INTERPOLATE BETWEEN RQD OF 40 AND 60 TO OBTAIN LINING COSTS
       CLL=CL40+(RQDD-40.)/20.*(CL60-CL40)
       CEL=CE40+(RQDD-40.)/20.*(CE60-CE40)
       CML=CM40+(RQDD-40.)/20.*(CM60-CM40)
C      ------------------------------------------------------------------
C      REINSTATE ORIGINAL VALUES OF RQD AND BOB
       RQD=RQDD
       BOB=BBOB
C      ------------------------------------------------------------------
C      UNIT COST OF FORMWORK EQUALS ZERO FOR SHOTCRETE
  525  IF(LINING.EQ.2) GO TO 2
C      LINING IS CONCRETE. CHECK FOR SUPPRESSED FORMWORK COSTS
       IF(NOFORM.GT.0) GO TO 2
       IF(ITYPE.EQ.2) GO TO 550
C      UNIT COST OF FORMWORK IN TUNNELS
       UCL=9.*BF*CFLCA
       IF(ISHAPE.EQ.1) X=2.2
       IF(ISHAPE.EQ.2) X=2.0
       IF(ISHAPE.EQ.3) X=1.6
       UCE=15.+X*BF
       UCM=0.18*BF
       AL=3.*HOURS
       IF(NSTYP.EQ.2) AL=AR
       GO TO 700
C      UNIT COST OF FORMWORK IN SHAFTS
  550  IF(ISHAPE.EQ.1) SFP=3.14
       IF(ISHAPE.EQ.2) SFP=4.
       UCL=25.+4.*BF
       UCE=(10.+1.5*BF)*SFP/3.14
       UCM=0.7*BF
       AL=8.*HOURS
       GO TO 700
```

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```
C     COMPUTE FORMWORK COSTS
  700 CLFW=(HOURS*CFLWWK+Y*DM)*UCL/AL
      CEFW=HOURS*CFEWWK*UCE/AL
      CMFW=UCM
      GO TO 1000
C     ***********************   CUT AND COVER   ***********************
  910 IF(ITYPE.EQ.2) GO TO 940
C     TUNNEL
      IF(LINING.EQ.3) GO TO 930
C     ------------------------------------------------------------------
C     CIP BOX
      UCL=480.-0.075*(70.-VL)**2
      UCE=55.-0.008*(65.-VL)**2
      UCM=26.*VL
      HOURCR=VL  *AR/(110.-0.03*(VL  -60.)**2)
      IF(HOURCR.LT.8.) HOURCR=8
      CLL=UCL*HOURCR/AR*CFLWWK
      CEL=UCE*HOURCR/AR*CFEWWK
      CML=UCM
      HOURCR=FORMAR*AR/(680.-0.004*(FORMAR-400.)**2)
      IF(HOURCR.LT.8) HOURCR=8
      CLFW=(100.+0.85*FORMAR)*HOURCR/AR*CFLWWK
      CEFW=(8.+(FORMAR+100.)**2/4500.)*HOURCR/AR*CFEWWK
      CMFW=0.35*FORMAR
      RETURN
C     ------------------------------------------------------------------
C     PRECAST CONCRETE BOX
  930 UCL=(0.07*(VL  +10.)**2-7.)*50./VL
      UCE=(0.007*(VL  +80.)**2-45.)*50./VL
      UCM=104.*VL
      HOURCR=VL*AR/50.
      IF(HOURCR.LT.8.) HOURCR=8
      CLL=UCL*HOURCR/AR*CFLWWK
      CEL=UCE*HOURCR/AR*CFEWWK
      CML=UCM
      GO TO 2
C     ------------------------------------------------------------------
C     SHAFT
  940 IF(ISHAPE.EQ.2) GO TO 945
      SFP=3.14
      GO TO 950
  945 SFP=4
  950 VL=(BF+TL)*TL*SFP/27.
      UCL= 0.07*(VL  +10.)**2-7.
      UCE= 0.007*(VL  +80.)**2-45.
      UCM=104.*VL
      CLL=UCL*CFLWWK
      CEL=UCE*CFEWWK
      CML=UCM
      GO TO 2
 1000 RETURN
      END
      SUBROUTINE CGROUT(CLG,CEG,CMG,ITYPE,GI,ISHAPE,BE,AR,RS,NSTYP,
     1MSTAB,     DTUN,HH,HOURS,CFLWWK,CFEWWK,SSEGL,PERM,SFP,DTG,TIMEG)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CGROUT CALCULATES THE COST OF GROUTING IN A TUNNEL OR SHAFT
```

(Continued)

```
C     SEGMENT
C     -----------------------------------------------------------------
C     -----------------------------------------------------------------
C
      IF(NSTYP.EQ.2) GO TO 500
      IF(NSTYP.EQ.3) GO TO 650
C     ****************************   ROCK   ***************************
      IF(ITYPE.EQ.2) GO TO 300
C     -----------------------------------------------------------------
C     TUNNEL
      IF(GI.GE.100.) GO TO 150
C     COST OF GROUTING EQUALS ZERO
  100 CLG=0
      CEG=0
      CMG=0
      RETURN
  150 IF(ISHAPE.EQ.1) SFP=3.14
      IF(ISHAPE.EQ.2) SFP=3.57
      IF(ISHAPE.EQ.3) SFP=2.66
      GT=0.005*SFP*BE*(1.+.01*GI)
      GO TO 400
C     -----------------------------------------------------------------
C     SHAFT
  300 IF(GI.LT.1.) GO TO 100
C     SHAFT IS WET,GROUTING REQUIRED
      SFP=3.14
      GT=0.01*SFP*BE
  400 CONTINUE
      HL=SFP*BE/4.
      UCL=0
      UCE=33.-0.015*(BE-46.)**2
      UCM=1.25*GT+RS*HL/200000.+0.075*HL-0.05*(BE-46.)**2/AR+100./AR
      GO TO 1000
C
C     **********************   SOFT GROUND   **************************
C     IS IT A SHAFT
  500 IF(ITYPE.EQ.2) GO TO 640
C     -----------------------------------------------------------------
C     TUNNEL
C     STABILIZED BY GROUND INJECTIONS
      IF(MSTAB.EQ.3) GO TO 550
      GO TO 650
C     IS TUNNEL CROWN DEEPER THAN 50 FT
  550 IF(ISHAPE.LE.2.AND. DTUN-BE/2..GT.50.) GO TO 600
      IF(ISHAPE.EQ.3 .AND. DTUN-BE/4..GT.50.) GO TO 600
C     GROUTING FROM GROUND SURFACE
      TIMEG=0.6+DTUN/20.+BE/40.
      IF(ISHAPE.EQ.3) TIMEG=0.6+DTUN/20.+BE/80.
      UCL=79.*(BE+10.)/25.*TIMEG*AR/HOURS
      UCE=15.*(BE+10.)/25.*TIMEG*AR/HOURS
      UCM=3.*TIMEG*(BE+10.)/25.+0.25*(BE+10.)**2*(0.55+0.15*ALOG10(SQRT
     1(10.*ABS(PERM))))/(1.55+0.15*ALOG10(SQRT(10.*ABS(PERM))))
      IF(ISHAPE.EQ.3) UCM=3.*TIMEG*(BE+10.)/25.+0.25*(BE+10.)*(0.5*BE+
     110.)*(0.55+0.15*ALOG10(SQRT(10.*ABS(PERM))))/(1.55+0.15*ALOG10(SQ
     2RT(10.*ACS(PERM))))
      GO TO 1000
C     GROUTING FROM EXCAVATION FACE
  600 UCL=0
```

(Continued)

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      UCE=3.4*BE
      UCM=0.14*BE+0.8*(0.55+0.15*ALOG10(SQRT(10.*ABS(PERM))))/
     1(1.55+0.15*ALOG10(SQRT(10.*ABS(PERM))))*BE*SFP
      GO TO 1000
C     ------------------------------------------------------------------
C     SHAFT
C     STABILIZED BY GROUND INJECTIONS
  640 IF(MSTAB.EQ.3) GO TO 700
  650 CLG=0.
      CEG=0.
      CMG=0.
      RETURN
C     IS SEGMENT MIDPOINT DEEPER THAN 200 FT
  700 IF(HH.GT.200.) GO TO 600
C     GROUTING FROM GROUND SURFACE
      UCL=79.*TIMEG*(BE+5.)*SFP/5./DTG*AR/HOURS
      UCE=15.*TIMEG*(BE+5.)*SFP/5./DTG*AR/HOURS
      UCM=0.6*TIMEG*(BE+5.)*SFP/DTG+0.64*(0.55+0.15*ALOG10(SQRT(10.*ABS
     1(PERM))))*(BE+5.)*SFP/(1.55+0.15*ALOG10(SQRT(10.*ABS(PERM))))
C     ------------------------------------------------------------------
C     COST OF GROUTING
 1000 CLG=UCL*HOURS*CFLWWK/AR
      CEG=UCE*HOURS*CFEWWK/AR
      CMG=UCM
      RETURN
      END
      SUBROUTINE CPUMP(CLP,CEP,CMP,NSTYP,FLOW,PH,PIPL,AR,
     1ITYPE,ELSURF,ELBOTM,DAYS,LINING,PUMPTM,MEX,DTRNCH,DROCK,FLOWL,
     2WELLS,RL,TIMEDW,ISUPPT,ELWATR,ELNPB,IWATER,CFLWWK,CFEWWK)
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C     CPUMP CALCULATES THE PUMPING COSTS
C     PUMPING TIME COMPUTED IN COSTSF IS FOR SOFT GROUND SHAFT ONLY
C     ASSUME PUMPING 24 HR A DAY , 7 DAYS A WEEK OPERATION
C     ------------------------------------------------------------------
C     ------------------------------------------------------------------
C
      IF(NSTYP.EQ.3) GO TO 300
C     ROCK OR SOFT GROUND
      IF(NSTYP.EQ.2) GO TO 100
C     ------------------------------------------------------------------
C     ROCK
```

(Continued)

```
C     SET COSTS=0
      UCL=0.
      UCE=0.
      UCM=0.
      GO TO 800
C     -----------------------------------------------------------------
C     DEEP WELL PUMPING
C     -----------------------------------------------------------------
C     SOFT GROUND
  100 IF(ITYPE.EQ.2) GO TO 250
C     -----------------------------------------------------------------
C     TUNNEL
      WELLLN=ELSURF-ELBOTM
C     PROVIDE 5 DAYS PUMPING AHEAD OF EXCAVATION TO REVERSE FLOW
C     PROVIDE 50 FT FINISHED LINING PAST PUMP BEFORE STOPPING ITEM
      IF(ISUPPT.LE.3) GO TO 180
C     STEEL RIBS WITH LINING
C     PROVIDE THE GREATER OF TIME TO FINISH 50 FT LINING AHEAD OF PUMP,
C     OR 30 CALENDAR DAYS FOR CURING OF CONCRETE
C     SHOTCRETE IS PLACED UP TO THE FACE.  CONCRETE IS KEPT 150 FT
C     BEHIND FACE.
      IF(50./AR*7./DAYS.GE.30.) GO TO 150
C     -----------------------------------------------------------------
C     PUMPING TIME CONTROLLED BY CURING TIME
C     CONCRETE
      IF(LINING.EQ.1) PUMPTM=35.+150./AR*7./DAYS
C     SHOTCRETE
      IF(LINING.EQ.2) PUMPTM=35.
      GO TO 450
C     -----------------------------------------------------------------
C     PUMPING TIME CONTROLLED BY PLACING RATE OF LINING
C     CONCRETE
  150 IF(LINING.EQ.1) PUMPTM=5.+200./AR*7./DAYS
C     SHOTCRETE
      IF(LINING.EQ.2) PUMPTM=5.+50./AR*7./DAYS
      GO TO 450
C     SEGMENTED SUPPORT
  180 PUMPTM=5.+50./AR*7./DAYS
      GO TO 450
C     -----------------------------------------------------------------
C     SHAFT
  250 IF(ELWATR.LT.ELNPB) GO TO 950
```

(Continued)

```
C     PUMPING TIME DETERMINED IN COSTSF
      WELLS=3
C     NO WELLS IF FLOW=0
      IF(FLOWL.LT.0.0001) WELLS=0
C     CONSIDER 1 FT LENGTH OF SHAFT
      WELLLN=1
      GO TO 450
C     ----------------------------------------------------------------
C     CUT-AND-COVER
  300 IF(ITYPE.EQ.2) GO TO 950
C     TUNNEL
      IF(ELWATR.LT.ELSURF-DTRNCH) GO TO 950
      IF(IWATER.EQ.0) GO TO 900
C     IS IT SOLDIER PILE WITH LAGGING
      IF(ISUPPT.EQ.5) GO TO 350
      IF(DROCK.LT.DTRNCH .AND. ELWATR.LT.ELSURF-DROCK) GO TO 950
      GO TO 400
C     IS ROCK LINE ABOVE TRENCH BOTTOM
  350 IF(DROCK.LT.DTRNCH) GO TO 900
  400 PUMPTM=(1./AR+(TIMEDW+10.)/RL)*7./DAYS
      IF(LINING.EQ.1) PUMPTM=(1./AR+(TIMEDW+40.)/RL)*7./DAYS
      WELLLN=DTRNCH
      IF(WELLLN.GT.DROCK) WELLLN=DROCK
  450 PIPED=0.5*FLOWL**0.4
      IF(PIPED.LT.1.) PIPED=1
C     SETUP COST OF DEEP WELLS
      UCL=(0.4*PIPED+3.2)*WELLLN*WELLS*AR/24.*DAYS/7.*CFLWUK/1.12
      UCE=(0.15*PIPED+1.)*WELLLN*WELLS*AR/24.*DAYS/7.*CFEWUK/0.715
      UCM=(0.75*PIPED+3.)*WELLLN*WELLS*AR/24.*DAYS/7.
C     OPERATING COST OF DEEP WELLS
      UCL=UCL+0.85*WELLS*PUMPTM*AR*DAYS/7.
      UCE=UCE+0.000265*FLOWL*PH*(0.0026+7./(2000.+0.000265*FLOWL*PH))*
     1WELLS*PUMPTM*AR*DAYS/7.
      UCM=UCM+5.*PH*FLOWL/1000000.*WELLS*PUMPTM*AR*DAYS/7.
C     SETUP
C     IS IT CUT-AND-COVER
      IF(NSTYP.EQ.3) GO TO 1000
C     SOFT GROUND
      IF(ITYPE.EQ.2) GO TO 1000
C     ----------------------------------------------------------------
C     PUMPING FROM TUNNEL
C     ----------------------------------------------------------------
```

(Continued)

```
C     --------------------------------------------------------------------
  800 IF(FLOW.GT.0.) GO TO 850
C     NO COST IF FLOW IS ZERO
      GO TO 1000
  850 IF(PH.LE.0.) GO TO 1000
      UCL=UCL+5.+11.*PH/3000.+0.003*PIPL
      UCE=UCE+(0.25+PH/2000.)*FLOW/500.
      UCM=UCM+5.*PH/1000.*FLOW/1000.
      GO TO 1000
C     --------------------------------------------------------------------
C     SUMP PUMPING
C     --------------------------------------------------------------------
  900 PUMPTM=(1./AR+10./RL)*7./DAYS
      IF(LINING.EQ.1) PUMPTM=(1./AR+40./RL)*7./DAYS
      UCL=5.*PUMPTM/500.*AR*DAYS/7.
      UCE=0.4*PUMPTM/500.*AR*DAYS/7.
      UCM=(0.15+0.0000044*PH*FLOWL)*PUMPTM/500.*AR*DAYS/7.
      GO TO 1000
C     SHAFT
  950 CLP=0.
      CEP=0.
      CMP=0.
      RETURN
C     --------------------------------------------------------------------
C     CALCULATE PUMPING COSTS
 1000 CLP=UCL*24/AR*7./DAYS*1.12
      CEP=UCE*24./AR*7./DAYS*0.715
      CMP=UCM*24./AR*7./DAYS
      RETURN
      END
      SUBROUTINE CAIRC(CLAC,CEAC,CMAC,Q,QT,BE,BF,AR,HOURS,NSTYP,MSTAB,
     1    ITYPE,AIRPR,    SFA,ISHAPE,HH,CAVT,ALOCK,DTC,DTCA,PUMPLT,DM,
     2          ALOCKL,UCMCP,CFLWWK,CFEWWK,DAYS,Y,PERM)
C     --------------------------------------------------------------------
C
C     CAIRC COMPUTES THE COSTS OF VENTILATION, AIR COOLING,
C     COMPRESSED AIR, AND AIR LOCKS
C     --------------------------------------------------------------------
      IF(NSTYP.EQ.3) GO TO 400
      IF(NSTYP.EQ.1) GO TO 50
      D10=SQRT(10.*ABS(PERM))
      IF(D10.LT.0.005) D10=0.005
C     SHAFT OR TUNNEL
   50 IF(ITYPE.EQ.2) GO TO 300
C     ****************************   TUNNELS    ************************
C     CHECK COOLING REQUIREMENT
      IF(Q.GT.0.) GO TO 100
C     NO COOLING
      UCLC=0.
      UCLMC=0.
      UCEC=0.
      UCMC=0.
      GO TO 200
C     COST OF SETUP AND OPERATION OF COOLING PLANT
  100 IF(ALOCK.GT.0.) UCLMC=QT*ALOCK/48.
      IF(ALOCK.LT.0.) UCLMC=QT*(1.-ALOCK)/48.
      UCLC=8.20
      UCEC=0.0000013*QT
      UCMC=0.0000009*Q
```

(Continued)

```
C       ----------------------------------------------------------------
  200 IF(MSTAB.NE.1) GO TO 60
C       COMPRESSED AIR
        CAV=(28.5+10.*ALOG10(D10))*SFA*BE**2
        ALOKA=ABS(ALOCK)
        UCLCA=16.4
C       COSTS OF AIR LOCK AND SETUP
        UCLLKA=20.4
        UCLLOK=(30000.+3.*HH)*(1.+0.25*(ALOKA-1.))
        UCELOK=(10000.+0.8*HH)*(1.+0.25*(ALOKA-1.))
        ALOCKD=BF
        IF(ISHAPE.EQ.3) ALOCKD=0.5*BF
        IF(ALOCKD.GT.15.) ALOCKD=15.
        IF(ALOCKL.LT.30.) ALOCKL=30.
        WALOCK=16.*ALOCKD*(ALOCKL+ALOCKD)
        VBULK=5.*(SFA*BF**2-0.785*ALOCKD**2)/27.
        UCMLOK=(1200.+0.1*HH)*(1.+0.25*(ALOKA-1.))+140.*VBULK*ALOKA
C       COST OF COMPRESSED AIR PLANT, SETUP AND OPERATION
        UCLMCA=0.075*(30000.+14.4*CAVT)*ALOKA
        UCECA=2.3+0.0011*CAVT
        UCMCA=0.003*CAV*(((AIRPR+14.7)/14.7+0.000123*PUMPLT)**0.242-1.)
        CLAC=(UCLLKA*HOURS/AR+UCLMC/DTC+(UCLMCA+UCLLOK)/DTCA)*CFLWWK
       1 +(UCLCA +UCLC)*24./AR*7./DAYS*1.12
        CEAC= (UCEC+UCECA)*24./AR*7./DAYS*0.715+UCELOK/DTCA*CFEWWK
        CMAC=(UCMC+UCMCA)*24./AR*7./DAYS+UCMCP+UCMLOK/DTCA
       1 +0.000015*WALOCK*HOURS/AR
        GO TO 500
C       ----------------------------------------------------------------
C       CALCULATE UNIT COSTS OF VENTILATION
   60 UCLV=3.*DM
        UCEV=0.5+0.625*SFA*BE**2/1000.
        UCMV=3.3*SFA*BE**2*DM/1000.
        UCMDFV=3.+SFA*BE**2/200.
        CLAC=UCLV*(HOURS*CFLWWK+0.5*Y*DM)/AR
        IF(DTC.GT.0.) CLAC=CLAC+(UCLMC/DTC+HOURS*UCLC/AR/4.)*CFLWWK
        CEAC=(UCEV+UCEC*HOURS/AR/4.)*CFEWWK
        CMAC=UCMDFV+HOURS*UCMV/AR+UCMC*HOURS/AR/4.
        GO TO 500
C       ****************************   SHAFTS   ************************
C       COMPRESSED AIR AND COOLING COSTS
  300 IF(NSTYP.EQ.1.OR.MSTAB.NE.1) GO TO 400
        CAV=(28.5+10.*ALOG10(D10))*SFA*BE**2
        Q=75.*CAV+20.*SQRT(CAV)+5000.
        UCLCA=8.20
        UCEC=0.0000013*Q
        UCECA=2.3+0.0011*CAV
        UCMC=0.0000009*Q
        UCMCA=0.003*CAV*(((AIRPR+14.7)/14.7+0.0025)**0.242-1.)
        CLAC=UCLCA*24./AR*1.12
        CEAC=(UCEC+UCECA)*24./AR*0.715
        CMAC=(UCMC+UCMCA)*24./AR
        GO TO 500
  400 CLAC=0.
        CEAC=0.
        CMAC=0.
C       ----------------------------------------------------------------
  500 RETURN
        END
```

(Continued)

```
      SUBROUTINE NEXSET(LO,LI)
      DIMENSION A(4),B(4)
      DATA A/4HEND ,4HOF S,4HYSTE,4HM
      WRITE(LO,1) A
    5 READ(LI,2) B
      DO 10 I=1,4
      IF(A(I).NE.B(I)) GO TO 5
   10 CONTINUE
      RETURN
    1 FORMAT(1H1,4A4)
    2 FORMAT(4A4)
      END
      SUBROUTINE ROCK(CLTS,CETS,CMTS,RQD,MEX,ISHAPE,BE,AR,RS,BE40,BE60,
     1ITYPE,Y,NSTYP,BF,ISUPPT,TPLATE,TSEG,PSOIL,WEB,PTCTAL,BOB,LINWT,
     2MSTAB,CFLCA,HOURS,CFLWWK,CFEWWK,SFA,LINING,DM,CLL,CEL,CML,
     3CLFW,CEFW,CMFW)
 1010 SFP=3.14
       YY=0.0
       S=4.0
       Y3=1.0
       UCL=Y3*(50.+.04*BE**2)
       UCE=Y3*(5.5+.003*(BE+10.)**2)
       UCM=Y3*(2.1+.001*BE**2)*HOURS/AR+YY
 1260 SEGN=3.
 1270 CJOINT=BE*SFP/S+SEGN
       UCL=UCL+.175*CJOINT*AR/HOURS
       UCE=UCE+.025*CJOINT*AR/HOURS
       UCM=UCM+.3*CJOINT
       VBACKG=SFA*(BE**2-(BE-.333)**2)
       UCL=UCL+1.3*VBACKG*AR/HOURS
       UCE=UCE+.5*VBACKG*AR/HOURS
       UCM=UCM+1.2*VBACKG
       CLTS=(HOURS*CFLWWK+Y*DM)*UCL/AR
       CETS=HOURS*CFEWWK*UCE/AR
       CMTS=UCM
       CLL=0.0
       CEL=0.0
       CML=0.0
       CLFW=0.0
       CEFW=0.0
       CMFW=0.0
       RETURN
       END
```

(Concluded)

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Bennett, Robert D.
Tunnel cost-estimating methods / by Robert D. Bennett (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1981.
238 p. in various pagings : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; GL-81-10)
Cover title.
"October 1981."
Final report.
"Prepared for Office, Chief of Engineers, U.S. Army under Project 4A762719AT40, Work Unit E0/005."
References: p. 50-52.

1. Cost. 2. Cost effectiveness. 3. Tunnels. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. U.S. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; GL-81-10.
TA7.W34m no.GL-81-10

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